Selcuk Dental Journal 11/3 (Aralık 2024): 341-345

Research / Araştırma Makalesi

Comparison of the Primary Stability of Orthodontic Mini-Screws Manufactured By Computer Numerically Control and Selective Laser Melting Manufacturing Methods: An Exploratory Study

Bilgisayar Sayısal Kontrollü ve Seçici Lazer Ergitme Üretim Yöntemleriyle Üretilen Ortodontik Mini Vidaların Birincil Stabilitesinin Karşılaştırılması: Keşifsel Bir Çalışma

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ABSTRACT

Objective: This study was to assess the primary stability of orthodontic mini-screws of the same design produced by a conventional and a novel manufacturing method.

Methods: A total of 150 orthodontic mini-screws with a body length of 8 mm, a diameter of 1.6 mm, a button head, and a self-drilling feature were used in the study. Mini-screws were manufactured through computer numerically controlled (CNC) and selective laser melting (SLM) manufacturing methods. Titanium (T) and stainless steel (SS) alloys were used as manufacturing materials. The study was conducted on three groups; CNC-T, SLM-T and SLM-SS. Mini-screws were placed at 60- and 90-degree angles in fresh bovine femur bones, where the cortical bone thickness was 2 mm. With the radiofrequency analysis (RFA) technique, the stability of the mini-screws was determined immediately after they were placed (F0), immediately after applying orthodontic force to the mini-screw (F1), after six hours (F6), and after 24 hours (F24). Three-way robust ANOVA was used to compare the data, and the Bonferroni correction was statistically applied.

Results: Except for the insertion angle of the mini-screw, the group and time factors had statistically significant effects on the RFA values. The highest RFA value was detected in the SLM-T group.

Conclusion: Additive manufacturing of orthodontic mini-screws using titanium and stainless steel alloys with SLM technology can be an alternative to traditional manufacturing. The mini-screws manufactured with SLM demonstrated sufficient primary stability when subjected to the required orthodontic forces.

Keywords: Orthodontic anchorage procedures, Bone screws, Computer-assisted manufacturing, Manufactured materials

ÖZ

Amaç: Bu çalışmanın amacı, geleneksel ve yeni bir üretim yöntemiyle üretilen aynı tasarıma sahip ortodontik mini vidaların primer stabilitesini değerlendirmekti.

Gereç ve Yöntemler: Çalışmada gövde uzunluğu 8 mm, çapı 1.6 mm, düğme başlıklı ve kendinden delme özelliğine sahip toplamda 150 adet ortodontik mini vida kullanıldı. Mini vidalar bilgisayarlı sayısal kontrollü (CNC) ve seçici lazer eritme (SLM) üretim yöntemleriyle üretildi. İmalat malzemesi olarak titanyum (T) ve paslanmaz çelik (SS) alaşımlar kullanıldı. Çalışma CNC-T, SLM-T ve SLM-SS olmak üzere üç grup üzerinde yürütüldü. Mini vidalar, kortikal kemik kalınlığının 2 mm olduğu taze sığır femur kemiklerine 60 ve 90 derecelik açılarla yerleştirildi. Mini vidaların primer stabiliteleri Radyofrekans analiz (RFA) tekniği ile mini vidalar yerleştirildikten hemen sonra (F0), mini vidalara ortodontik kuvvet uygulandıktan hemen sonra (F1), 6 saat sonra (F6) ve 24 saat sonra (F24) ölçüldü. Verileri karşılaştırmak için üç yönlü robust ANOVA test istatistiği kullanıldı ve Bonferroni düzeltmesi uygulandı.

Bulgular: Mini vidaların yerleştirme açısı dışında, grup ve zaman faktörlerinin RFA değerleri üzerinde istatistiksel olarak anlamlı etkileri vardı. En yüksek RFA değeri SLM-T grubunda tespit edildi.

Sonuçlar: SLM teknolojisi kullanılarak titanyum veya paslanmaz çelik alaşımlardan üretilen ortodontik mini vidalar, geleneksel üretim yöntemi kullanılarak üretilen mini vidalara alternatif olabilir. SLM teknolojisi kullanılarak üretilen mini vidalar, ortodontik kuvvete maruz kaldıklarında yeterli primer stabilite göstermişlerdir.

INTRODUCTION

An anchorage refers to a resistance to unwanted tooth movement in the context of orthodontics.[1] While numerous intraoral and extraoral devices can be utilized in anchorage control, the clinical benefits of these devices may be constrained due to the need for patient cooperation.[2] Mini-screws have emerged as excellent alternatives for anchorage in contemporary orthodontic treatments due to their numerous advantages over traditional orthodontic anchorage methods.[3] Primary stability is defined as the mechanical locking that occurs between the threaded surface of the mini-screw and the underlying bone after its insertion.[4] This process is influenced by various factors, including the characteristics of the mini-screw in question, the patient's condition, the tissue surrounding it, the practitioner's expertise, and the loading conditions.[5] Primary stability can also be affected by other factors, such as the manufacturing method, production material, and physical properties of the mini-screw itself.

Orthodontic mini-screws are typically manufactured using conventional subtractive manufacturing processes on computer numerically controlled (CNC) machines. CNC is an overarching term encompassing various machine types with multiple sizes, shapes, and functions. The CNC machine is a motorized machine that shapes materials by removing chips. However, the fundamental philosophy of CNC production is the cutting of solid material blocks and the creation of desired objects via computer control.[6] The disadvantages of CNC technology include the high investment cost, the need for meticulous maintenance and use, and the requirement for quality and expensive equipment. CNC machines are widely used in the manufacture of dental materials. The integration of technological developments into the field of dentistry leads to a transformation in the treatment approaches applied to patients and the products used in treatment. A new manufacturing technology called selective laser melting (SLM) has recently been used in dentistry. The SLM method is a technique that can create complex structures and does not require and minimize post-processing on the materials manufactured. With the SLM method, three-dimensional prostheses which is the part of the arbitrarily complex structures are produced by combining metal powders layer by layer with a computer-controlled laser. [7] It has been reported in the literature that innovative additive technology offers several advantages over casting and milling fabrication techniques, including improved mechanical and electrochemical properties and the ability to deliver more cost-effective restorations more quickly. The number of publications in this field is on a continual rise each year. The enhancement of SLM equipment performance and the incremental optimization of the SLM

Gönderilme Tarihi/Received: 7 Haziran, 2024
Kabul Tarihi/Accepted: 15 Ekim, 2024
Yayınlanma Tarihi/Published: 23 Aralık, 2024
Atıf Bilgisi/Cite this article as: Öztürk Yaşar M, Irgın C. Comparison of the Primary Stability of Orthodontic Mini-Screws Manufactured By Computer Numerically Control and Selective Laser Melting Manufacturing Methods: An Exploratory Study. Selcuk Dent J 2024;11(3): 341-345 Doi: 10.15311/ selcukdentj.1497317

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Doi: 10.15311/ selcukdentj.1497317

forming process have resulted in a notable increase in related research projects over the past three years, particularly since 2020.[8]

Orthodontic mini-screws are generally manufactured from titanium alloy. However, the demand for titanium alloy has increased due to its use in various industrial fields, making it more expensive in terms of cost.[9] Therefore, in some countries, stainless steel mini-screw is more commonly used than titanium alloy in manufacturing.[10] Stainless steel is one of the most used oral surgical and orthopedic implant materials due to its mechanical properties, biocompatibility, cost-effectiveness, and ease of manufacturing.[11] Although there is extensive literature on titanium alloy mini-screws, reports on using stainless steel mini-screws are scarce.[10]

One factor affecting primary stability is the insertion angle of the mini-screw. There needs to be more consensus regarding the ideal insertion angle in the literature. Some authors recommend oblique mini-screw insertion to avoid root contact,[12] while others have argued that the placement angle does not affect primary stability.[9]

The study aimed to compare the primary stability of titanium mini-screws manufactured through CNC and titanium and stainless steel mini-screws manufactured through SLM by inserting them into fresh bone blocks at 60° and 90° angles and investigate the effects of the mini-screw production methods, manufacturing materials and minis-crew insertion angle on primary stability. The study's null hypothesis was that there was no difference between the primary stability of titanium and stainless steel mini-screws manufactured through the CNC and SLM methods.

MATERIAL AND METHODS

Specimen's preparation

This in-vitro study was approved by the Clinical Research Ethics Committee at Erciyes University (Decision No: 2022/447). The sample size was calculated with the G*Power Ver. 3.1.9.7 (Franz Faul, Universität Kiel, Germany) software. When α = 0.05 and β = 0.90 in the power analysis, based on a 1:1 ratio between groups [effect size (d) = 1.00], it was calculated that at least 23 mini-screws were required for each group. In the study, 50 titanium mini-screws manufactured through CNC (Tomas® Anchorage System, Dentaurum, Germany), 50 titanium, and 50 stainless steel mini-screws manufactured through SLM (Custimesh Private Health Services, Kayseri, Türkiye) with the same design (body length 8 mm, diameter 1.6 mm, button head, self-drilling) were used (**Figure 1 and Table 1**). The length, neck diameter, body diameter, and tip diameter of all mini-screws were measured by the same investigator (CI) with a precision caliper to verify that they met the standard parameters.

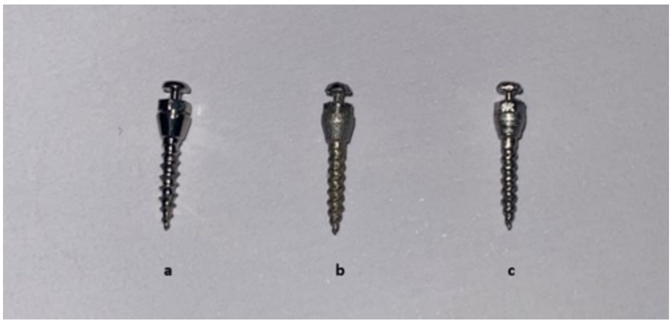

Figure 1. a) CNC Titanium (CNC-T), **b)** SLM Titanium (SLM-T), **c)** SLM Stainless Steel (SLM-SS) mini-screws.

Table 1. Description of mini screws used in the study according to groups.

Groups	CNC-T	SLM-SS	SLM-T
Manufacturing method	Computer Numerically Controlled (CNC)	Selective Laser Melting (SLM)	Selective Laser Melting (SLM)
Production material	Titanium Alloy (T)	Stainless Steel Alloy (SS)	Stainless Steel Alloy (SS)
Design	Body length 8 mm Diameter 1.6 mm Button head Self-drilling	Body length 8 mm Diameter 1.6 mm Button head Self-drilling	Body length 8 mm Diameter 1.6 mm Button head Self-drilling
Insertion angle	60° / 90°	60° / 90°	60° / 90°
Number of mini screws	25 / 25 (n=50)	25 / 25 (n=50)	25 / 25 (n=50)

Fresh bone blocks were obtained from bovine femur bones and found in the literature to be compatible with the thickness of cortical bone in human jaws.[13-15] Bone blocks were obtained daily. The suitable bone surfaces where the mini-screws were to be inserted were determined with Cone Beam Computer Tomography (CBCT) (NewTom 5G, QR, Verona, Italy) (**Figure 2**). Regions with a cortical bone thickness of 2 mm were defined as suitable sites (**Figure 3**). After the fresh bone blocks were fixed using a bone splint, mini-screws were inserted into the previously determined bone surfaces at angles of 60 and 90 degrees with the assistance of an angled apparatus. Consequently, 25 of the totals 50 mini-screws in each experimental group were placed at an angle of 60°, while the remaining 25 were positioned at an angle of 90°.

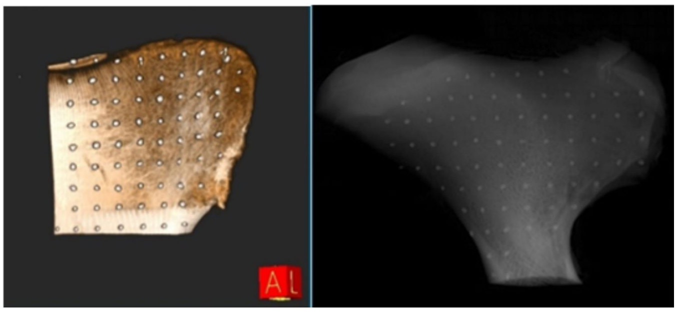

Figure 2. Measurement of cortical bone thickness of marked points on fresh bone blocks on the CBCT images.

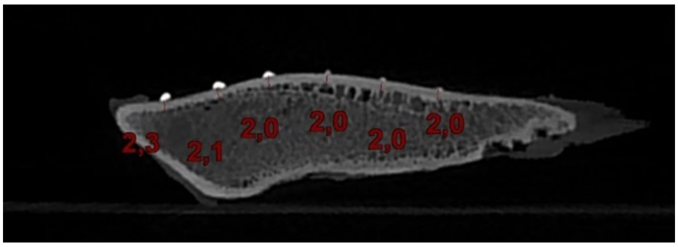

Figure 3. Measuring cortical bone thickness on cut and marked bone blocks.

Radiofrequency analysis (RFA) was utilized to measure the primary stability of the mini-screws. For this purpose, the Ostell device (Ostell® ISQ, Goteborg, Sweden) was used. The smartpeg part of the Ostell device was placed on the heads of the mini-screws with the help of a spacer designed to be compatible with the heads of the mini-screws, and then RFA measurements were made (**Figure 4**). After the first RFA measurement just before force application (F0), 150 g orthodontic force was applied to the mini-screws using closed coil springs. RFA measurements were repeated immediately after force application (F1), six hours later (F6), and 24 hours later (F24). Measurements were made from four directions in the horizontal plane for all mini-screws. A single implant stability quotient (ISQ) value was calculated by taking the arithmetic mean of the measurements. To ensure the reliability of the measurement process, the measurements were carried out by a single researcher (MÖY).

Figure 4. Measurement of the stability of mini-screws with the Ostell device.

Statistical analysis

The data were analyzed with the IBM SPSS 23 software, R software, and WRS2 package. Three-way Robust ANOVA was used to compare the data according to group, time, and angle, and the Bonferroni correction was made for multiple comparisons. The data analyzed are presented as the trimmed mean and standard error of the mean. The significance level was taken as $p<0.05$.

RESULTS

The significance of the interactions of the group, angle, and time variables of the RFA values (ISQ) measured at F0, F1, F6, and F24 periods of the mini-screw groups are presented in **Table 2**, and the descriptive statistics and multiple comparisons are shown in **Table 3**.

Table 2. Comparison of the effects of interactions of group, angle, and time variables on the Resonance Frequency Analysis (RFA) values (ISQ)

Variables	Q	p value
Group	273,066	< 0.001
Angle	0,032	0.860
Time	29,287	0.001
Group * Angle	6,676	0.040
Group * Time	151,554	0.001
Angle * Time	53,547	0.001
Group * Angle * Time	92,447	0.001

Q: ROBUST ANOVA Test Statistics, Statistical significance p<0.05.

The effect of the group variable on the RFA values was found to be statistically significant ($p<0.001$) (**Table 2**), and the highest value obtained was 48.3 (ISQ) in the SLM-T group (**Table 3**). However, the influence of the angle variable on the RFA values was not statistically significant ($p>0.05$) (**Table 2**). The impact of the time variable on the RFA values was found to be statistically significant ($p<0.001$) (**Table 2**), and the value obtained in the F6 period differed from the values obtained in the F1 and F24 periods (**Table 3**).

The interaction of group and angle variables had a statistically significant effect on the RFA values ($p<0.05$) (**Table 2**). The highest total value was obtained at a 90° angle in the SLM-T group and similarly at a 60° angle in the same group (**Table 3**). All other groups and angle interactions differed from these values. The combined interaction of the group and time variables had a statistically significant effect on the RFA values ($p<0.001$) **(Table 2)**. The highest value was obtained in the SLM-T group after the F24 period, and the lowest value was obtained in the SLM-SS group after the F0 period (**Table 3**). The association of the angle and time variables had a statistically significant effect on the RFA values ($p<0.001$) (**Table 2**). The highest value was obtained in the F1 period at a 90° angle and the lowest in the F6 period at a 90° angle (**Table 3**). The interaction of group, time, and angle variables statistically significantly affected the RFA values ($p<0.001$) (**Table 2**). The highest total value was found in the SLM-T group at an angle of 90° and after the F24 period, and the lowest was found in the SLM-SS group at an angle of 90° and in the F0 period (**Table 3**).

Table 3. Descriptive statistics and multiple comparison results of the Resonance Frequency Analysis (RFA) values (ISQ)

Time	Angle	Group			
		CNC-T	SLM-SS	SLM-T	Total
		Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Immediately before applying force (F0)	60°	46,1 ± 0,53^{ABCDEF}	41,1 ± 1,46^{ABCDEG}	48,7 ± 0,16^{HİK}	46,2 ± 0,54^{ABC}
	90°	49,6 ± 0,55^{HİJ}	40,8 ± 0,63^{G}	48,6 ± 0,51^{FHİJKL}	46,7 ± 0,71^{ABC}
	Total	47,6 ± 0,5^{ABCD}	40,8 ± 0,57^{H}	48,7 ± 0,25^{CD}	46,4 ± 0,43^{ab}
Immediately after applying force (F1)	60°	44,1 ± 0,58^{ABEG}	45,8 ± 0,35^{ABCE}	47,3 ± 0,27^{CDFJL}	46 ± 0,28^{AB}
	90°	48,8 ± 0,25^{HİK}	46,4 ± 0,52^{BCDEFKL}	47,8 ± 0,27^{DFHİJKL}	47,8 ± 0,22^{C}
	Total	46,8 ± 0,54^{ABCEF}	46,1 ± 0,35^{AEF}	47,5 ± 0,2^{B}	46,9 ± 0,19^{a}
6 hours after applying force (F6)	60°	43,5 ± 0,77^{ABEG}	47,6 ± 0,47^{CDFHİJKL}	47,6 ± 0,24^{CDFHİJKL}	46,6 ± 0,33^{AC}
	90°	41,7 ± 0,43^{G}	43 ± 0,69^{ABG}	48,8 ± 0,34^{HİJKL}	44,3 ± 0,6^{B}
	Total	42,4 ± 0,48^{GH}	45,2 ± 0,54^{EF}	48 ± 0,2^{BC}	45,6 ± 0,36^{b}
24 hours after applying force (F24)	60°	46 ± 0,41^{ABCDEF}	46,7 ± 1,22^{ABCDEFGHİJKL}	48,9 ± 0,29^{HİJKL}	47,3 ± 0,31^{C}
	90°	41,7 ± 1^{AG}	47,1 ± 0,42^{CDEFHJKL}	49,8 ± 0,49^{İ}	46,8 ± 0,46^{AC}
	Total	44,5 ± 0,65^{EG}	47,1 ± 0,34^{ABF}	49,2 ± 0,28^{D}	47,1 ± 0,25^{a}
Total	60°	45,1 ± 0,26^{A}	45,9 ± 0,42^{A}	48 ± 0,14^{B}	46,5 ± 0,18
	90°	45,9 ± 0,63^{A}	44,4 ± 0,39^{A}	48,6 ± 0,17^{B}	46,6 ± 0,25
	Total	45,4 ± 0,32^{a}	45,1 ± 0,32^{a}	48,3 ± 0,13^{b}	46,6 ± 0,16

ROBUST ANOVA Test Statistics, mean ± standard error (SE), a-b: There is no difference between main effects with the same letter, A-D: There is no difference between interactions with the same letter.

DISCUSSION

This study investigated the primary stability of orthodontic mini-screws with the same design manufactured through different methods (CNC and SLM) and materials (titanium and stainless steel alloys). The unique aspect of this study is that the SLM technology, a form of additive manufacturing technique, is being applied to the field of orthodontics for the first time to manufacture orthodontic mini-screws. The mini-screws were inserted into fresh bone blocks with a cortical thickness of 2 mm to provide standard test conditions. An equal orthodontic force was applied to the mini-screws, and measurements were performed with the same device. The test statistic indicated that the ISQ value of the SLM-T group was significantly higher than those of the CNC-T and SLM-SS groups, while there was no difference between the CNC-T and SLM-SS groups. Based on these findings, the null hypothesis of the study was rejected. Although the designs of the mini-screws were the same, the primary stability of the mini-screws was affected due to different manufacturing methods and materials. However, the insertion angle of the mini-screws, be it oblique or perpendicular (60 or 90 degrees), did not affect the primary stability.

The manufacturing method was the same in the SLM-T and SLM-SS groups, but the materials differed. Higher RFA values were obtained in the SLM-T group because titanium had higher stability values as a material than stainless steel. Indeed, Brown et al.[16] reported that stainless steel mini-screws lack absolute osseointegration and have lower stability than titanium mini-screws. While the manufacturing methods differed in the CNC-T and SLM-T groups, the manufacturing materials of the mini-screws were the same. The higher value obtained in the SLM-T group is due to the manufacturing method used by the groups. The difference in primary stability between the two production methods may be due to the microstructure morphology of the mini-screws.

The integration of technological developments in the field of orthodontics with patient-oriented treatment methods has resulted in a fundamental evolution in the equipment used in the treatment process. The most prominent example today is aligners, which are manufactured using additive manufacturing techniques.[17] The need for orthodontic mini-screws to provide the necessary anchorage or desired tooth movement is also increasing as the use of aligners becomes more widespread.

The authors state that if the mini-screw is to be loaded immediately, the force range should be limited to 50-300 g.[9,18] In this study, 150 g force was applied to the mini-screw per this force range. Previous studies have shown that the immediate loading of mini-screws does not harm their stability.[9,19-21] Melsen et al.[22] stated that immediate force loading positively affected the bone and increased cellular turnover and density in the areas adjacent to the loaded mini-screw compared to the unloaded mini-screw and that orthodontic loading may have a protective effect. This finding is consistent with Manni et al.[23] and Kuroda et al.[24] who reported that immediate load positively and significantly affected the success rate. Our study found a similar increase in the RFA values after force application. Although fresh bone was used in this study, cellular changes were limited. Therefore, the observed increase in the RFA values after the application of force in the groups may be explained by the rise in the bone-screw contact with the micro-level bending of the mini-screw in the direction of the force.

The literature shows no agreement regarding different mini-screw insertion angles.[12,25] Some investigators reported that mini-screw insertion angles affect primary stability by causing an increase in cortical bone contact.[12,26] In contrast, other investigators[27] reported that mini-screw insertion angles did not affect primary stability, which was also found in this study. However, regardless of the insertion angle, when the RFA values were evaluated, the F1, F6, and F24 values were similar to those obtained in the F0 period. Based on this finding, it can be stated that all mini-screws used in the study were generally resistant to orthodontic forces of 150 g and that force application did not significantly negatively affect primary stability.

The limitations of our study are that mini-screws manufactured through the SLM method could not be tested on living tissues, and the surface properties of mini-screws were not examined microscopically. Further studies on these areas are needed.

CONCLUSION

The following conclusions may be drawn from the results of this study:

- The mini-screws in all groups exhibited sufficient primary stability for clinical use. No mini-screw failure occurred during the trial.
- For mini-screws of the same design, the manufacturing technique and the material used in production affect the primary stability.
- Insertion of the mini-screw at 60 or 90 degrees does not affect primary stability.
- The selective laser melting (SLM) manufacturing method provided an innovative approach to the three-dimensional manufacturing of orthodontic mini-screws.

Acknowledgments

The authors would like to express their gratitude to Prof. Dr. İbrahim Yavuz for his invaluable support of the study and to Benlioglu Dental, the distributor of Dentaurum in Türkiye, for their contribution to the supply and manufacturing of mini-screws.

Değerlendirme / Peer-Review

İki Dış Hakem / Çift Taraflı Körleme

Etik Beyan / Ethical statement

Bu makale, sempozyum ya da kongrede sunulan bir tebliğin içeriği geliştirilerek ve kısmen değiştirilerek üretilmemiştir.

Bu çalışma Dr. Öğr. Üyesi Celal Irgın'ın danışmanlığında 28/12/2023 tarihinde sunulan/tamamlanan "Farklı yöntemler ile imal edilen minividalarda üretim materyalinin, yerleştirme açısının ve sterilizasyon sonrası yeniden kullanımın primer stabilite üzerine etkilerinin karşılaştırılması" başlıklı Diş Hekimliğinde uzmanlık tezi esas alınarak hazırlanmıştır.

Bu çalışmanın hazırlanma sürecinde bilimsel ve etik ilkelere uyulduğu ve yararlanılan tüm çalışmaların kaynakçada belirtildiği beyan olunur.

This article is not the version of a presentation.

This study was prepared under the supervision of Assistant Professor Celal Irgın on the basis of the thesis for specialization in dentistry entitled "Comparison of the effects of production material, insertion angle and reuse after sterilization on the primary stability of miniscrews manufactured by different methods" dated 28.12.2023.

It is declared that during the preparation process of this study, scientific and ethical principles were followed and all the studies benefited are stated in the bibliography.

Benzerlik Taraması / Similarity scan

Yapıldı – ithenticate

Etik Bildirim / Ethical statement

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Finansman / Grant Support

Yazarlar bu çalışmanın Erciyes Üniversitesi Araştırma Projeleri Birimi (proje numarası 12149) tarafından finanse edildiğini beyan etmişlerdir. | The authors declare that this study was financed by Erciyes University Research Projects Unit (project number 12149).

Çıkar Çatışması / Conflict of Interest

Yazarlar çıkar çatışması bildirmemiştir. | The authors have no conflict of interest to declare.

Yazar Katkıları / Author Contributions

Çalışmanın Tasarlanması | Design of Study: MÖY (%20), CI (%80)
Veri Toplanması | Data Acquisition: MÖY (%90), CI (%10)
Veri Analizi | Data Analysis: MÖY (%50), CI (%50)
Makalenin Yazımı | Writing up: MÖY (%40), CI (%60)
Makale Gönderimi ve Revizyonu | Submission and Revision: MÖY (%10), CI (%90)

REFERENCES

1. Proffit WR, Fields HW, Larson B, Sarver DM. Contemporary Orthodontics e-book. Amsterdam: Elsevier Health Sciences; 2018.
2. Sherman AJ. Bone reaction to orthodontic forces on vitreous carbon dental implants. Am J Orthod. 1978;74:79–87.
3. Schnelle MA, Beck FM, Jaynes RM, Huja SS. A radiographic evaluation of the availability of bone for placement of miniscrews. Angle Orthod. 2004;74:832–837.
4. Wilmes B, Rademacher C, Olthoff G, Drescher D. Parameters affecting primary stability of orthodontic mini-implants J Orofac Orthop. 2006;67:162–74.
5. Chen Y, Kyung HM, Zhao WT, Yu WJ. Critical factors for the success of orthodontic mini-implants: a systematic review. Am J Orthod Dentofacial Orthop. 2009;135:284–291.
6. Your CNC Machine. In: Build Your Own CNC Machine. Berkeley, CA: Apress; 2009;1–4.
7. Ahmadi M, Tabary SAAB, Rahmatabadi D, Ebrahimi MS, Abrinia K, Hashemi R. Review of selective laser melting of magnesium alloys: advantages, microstructure and mechanical characterizations, defects, challenges, and applications. J Mater Res Technol. 2022;19:1537–1562.
8. Wen S, Gan J, Li F, Zhou Y, Yan C, Yusheng Shi Y. Research status and prospect of additive manufactured nickel-titanium shape memory alloys. Materials (Basel). 2021;14(16):4496.
9. Park HS, Jeong SH, Kwon OW. Factors affecting the clinical success of screw implants used as orthodontic anchorage. Am J Orthod Dentofacial Orthop. 2006;130:18–25.
10. Pan CY, Chou ST, Tseng YC, Yang YH, Wu CY, Lan TH, et al. Influence of different implant materials on the primary stability of orthodontic mini-implants. Kaohsiung J Med Sci. 2012; 28:673–678.
11. Disegi JA, Eschbach L. Stainless steel in bone surgery. Injury. 2000; 31 Suppl 4:2–6.
12. Wilmes B, Su YY, Drescher D. Insertion angle impact on primary stability of orthodontic mini-implants. Angle Orthod. 2008;78:1065–1070.
13. Ono A, Motoyoshi M, Shimizu N. Cortical bone thickness in the buccal posterior region for orthodontic mini-implants. Int J Oral Maxillofac Surg. 2008;37:334–340.
14. Deguchi T, Nasu M, Murakami K, Yabuuchi T, Kamioka H, Takano-Yamamoto T. Quantitative evaluation of cortical bone thickness with computed tomographic scanning for orthodontic implants. Am J Orthod Dentofacial Orthop. 2006;129:721.e7-12.
15. Baumgaertel S, Hans MG. Buccal cortical bone thickness for mini-implant placement. Am J Orthod Dentofacial Orthop. 2009;136:230–235.
16. Brown RN, Sexton BE, Gabriel Chu TM, Katona TR, Stewart KT, Kyung HM, et al. Comparison of stainless steel and titanium alloy orthodontic miniscrew implants: a mechanical and histologic analysis. Am J Orthod Dentofacial Orthop. 2014;145:496–504.
17. Jeong M, Radomski K, Lopez D, Liu JT, Lee JD, Lee SJ. Materials and Applications of 3D Printing Technology in Dentistry: An Overview. Dent J (Basel). 2024; 12(1):1.
18. Melsen B. Mini-implants: Where are we? J Clin Orthod. 2005; 39: 539–547.
19. Büchter A, Wiechmann D, Koerdt S, Wiesmann HP, Piffko J, Meyer U. Load-related implant reaction of mini-implants used for orthodontic anchorage. Clin Oral Implants Res. 2005;16:473–479.
20. Melsen B, Costa A. Immediate loading of implants used for orthodontic anchorage. Clin Orthod Res. 2000; 3: 23–28.
21. Wiechmann D, Meyer U, Büchter A. Success rate of mini- and micro-implants used for orthodontic anchorage: a prospective clinical study. Clin Oral Implants Res. 2007;18: 263–267.
22. Melsen B, Lang NP. Biological reactions of alveolar bone to orthodontic loading of oral implants. Clin Oral Implants Res. 2001;12:144–152.
23. Manni A, Cozzani M, Tamborrino F, De Rinaldis S, Menini A. Factors influencing the stability of miniscrews. A retrospective study on 300 mini-screws. Eur J Orthod. 2011;33:388–395.
24. Kuroda S, Sugawara Y, Deguchi T, Kyung HM, Takano-Yamamoto T. Clinical use of miniscrew implants as orthodontic anchorage: success rates and postoperative discomfort. Am J Orthod Dentofacial Orthop. 2007;131: 9–15.
25. Araghbidikashani M, Golshah A, Nikkerdar N, Rezaei M. In-vitro impact of insertion angle on primary stability of miniscrews. Am J Orthod Dentofacial Orthop. 2016;150:436–443.
26. Park HS, Bae SM, Kyung HM, Sung JH. Micro-implant anchorage for treatment of skeletal Class I bialveolar protrusion. J Clin Orthod. 2001;35:417–422.
27. Miyawaki S, Koyama I, Inoue M, Mishima K, Sugahara T, Takano-Yamamoto T. Factors associated with the stability of titanium screws placed in the posterior region for orthodontic anchorage. Am J Orthod Dentofacial Orthop. 2003;124: 373–378.