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YEDİTEPE UNIVERSITY
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AN EVALUATION ON THE EFFECT OF THE MIR APPLIANCE ON THE FORCE RESISTANCE AND STABILITY OF MINI SCREWS OF DIFFERENT LENGTHS AND DIAMETERS

DOCTOR OF PHILOSOPHY THESIS

DT. ILGAZ ÖZER

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This thesis has been deemed by the jury in accordance with the relevant articles of Yeditepe University Graduate Education and Examinations Regulation and has been approved by Administrative Board of Institute with decision dated .... and numbered ....

Director of Institute of Health Sciences

DECLARATION

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree except where due acknowledgment has been made in the text.

25/01/2022
Ilgaz ÖZER

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ABBREVIATIONS

MIR	:	Mini Implant Ring
TM	:	Trimed
MAT	:	Maximum Aplication Torque
MET	:	Maximum Extraction Torque
gr	:	Gram
°	:	Degree
SLA	:	Sintered, large-grid, acid etched
MPa	:	Mega Pascal
SD	:	Standart Deviation
cm	:	Centimeter
N	:	Newton
Ncm	:	Newton Centimeter
n	:	Number of Sample
mm	:	Milimeter
p	:	Probability
%	:	Percent
CT	:	Computed Tomography
FEA	:	Finite Element Analysis
RFA	:	Resonance Frequency Analysis
µCT	:	Microtomograhy
FR	:	Force Resistance
CBT	:	Cortical Bone Thickness

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ABSTRACT

Özer, I. (2021). An Evaluation on The Effect of the MIR Appliance on the Force Resistance and Stability of Mini Screws of Different Lengths and Diameters. Yeditepe University, Institute of Health Science, Department of Orthodontics, PhD thesis, Istanbul.

The present study aims to investigate the effect of the mini-implant ring (MIR) appliance on force resistance and stabilization when used in vitro with mini screws of different lengths and diameters. A total of 120 TM (Trimed, Ankara, Turkey) mini screws, including 20 pieces of 1.4 mm diameter and 6 mm length, 20 pieces of 1.4 mm diameter and 8 mm length, 20 pieces of 1.6 mm diameter and 6 mm length, 20 pieces of 1.6 mm diameter and 8 mm length, 20 pieces of 1.8 mm diameter and 6 mm length, and 20 pieces of 1.8 mm diameter and 8 mm length were used for the study. Titanium TM mini screws with a conical structure and "self-drilling" feature were preferred in the study. The other group in which the MIR was not applied was used as the control group. Mini screws were applied to samples obtained from bovine hip bones, in the laboratory using a torque screwdriver (N2DPSK, Nakamura MFG Co Ltd, Tokyo, Japan) and maximum application torque (MAT) values were measured. Then, by applying force perpendicular to the long axis of the mini screw with an Instron tester, the resistance values of the mini screws up to a 0.6 mm displacement were recorded. Following the evaluation of the mobility of the force-tested mini screws, the mini screws were removed from the bone by measuring their maximum extraction torques (MET) with a torque meter screwdriver. The statistical analysis showed that application torques increased in mini screws to which the MIR appliance was applied, and this increase did not exceed desired levels. A nonsignificant increase in extraction torques was also recorded. These results show that the MIR apparatus is effective in increasing the force resistance and stability particularly of smaller diameter mini screws to a certain extent.

As a result of the research, the MIR apparatus is recommended as a good option, especially in cases where the cortical bone is thin or a smaller diameter mini screw is preferred, since it increases the primary stability and force resistance of the mini screw.

Keywords: Mini screw, MIR appliance, stability, force resistance, screw diameter, screw length

ÖZET

Özer, I. (2021). MIR apareyinin farklı uzunluk ve çaptaki minividaların kuvvet direnci ve stabilitesine olan etkisinin değerlendirilmesi. Yeditepe Üniversitesi Sağlık Bilimleri Enstitüsü, Ortodonti ABD., Doktora Tezi. İstanbul.

Çalışmamızın amacı, in vitro ortamda MIR apareyinin farklı uzunluk ve çaptaki minividalarla beraber kullanıldıklarında kuvvet direnci ve stabilizasyona olan etkisinin araştırılmasıdır. Çalışmamızda 1,4 mm çapında 6 mm uzunluğunda 20 adet, 1,4 mm çapında 8 mm uzunluğunda 20 adet, 1,6 mm çapında 6 mm uzunluğunda 20 adet, 1,6 mm çapında 8 mm uzunluğunda 20 adet, 1,8 mm çapında 6 mm uzunluğunda 20 adet, 1,8 mm çapında 8 mm uzunluğunda 20 adet olmak üzere toplam 120 adet TM (Trimed, Ankara, Türkiye) minivida kullanılmıştır. Bu araştırmada, konik yapıda olan TM minividalar tercih edilmiştir. TM minividalar, ‘’Self- drilling’’ özelliğe sahiptir ve titanyumdan üretilmişlerdir. MİR uygulanmayan diğer grup ise kontrol grubu olarak kullanılmıştır. Minividalar, laboratuvar ortamında, sığır kalça kemiğinden elde edilen örneklere tork ölçer tornavida (N2DPSK, Nakamura MFG Co Ltd, Tokyo, Japan) ile uygulanmış ve maksimum uygulama torku (MUT) değerleri ölçülmüştür. Daha sonra, Instron test cihazı ile minivida uzun eksenine dik yönde kuvvet uygulanarak, 0,6 mm yer değiştirene kadar gösterdikleri direnç değerleri kaydedilmiştir. Kuvvet testi uygulanmış minividaların mobilitelerinin değerlendirilmesini takiben minividalar tork ölçer tornavida ile maksimum çıkarma torku (MÇT) ölçülerek kemikten çıkarılmıştır. Yapılan istatistiksel analizde MİR aparatı kullanılan minividalarda uygulama torkları artmıştır ve bu artış istenen seviyeleri aşmamıştır. Çıkarma torklarında da anlamlılık seviyesinde olmayan bir artış kaydedilmiştir. Bu sonuçlar, MİR aparatının özellikle daha küçük çaplı minividaların kuvvet direncini ve stabilitesini belli ölçülerde arttırmada etkili olduğunu ortaya koymaktadır.

Yapılan araştırma sonucunda MİR aparatı, minivida primer stabilitesi ve kuvvet direncini arttırmasından dolayı özellikle kortikal kemiğin ince olduğu veya daha küçük çaplı minivida tercih edildiği vakalarda iyi bir seçenek olarak tavsiye edilmektedir.

Anahtar Kelimeler: Minivida, MİR aparatı, stabilite, kuvvet direnci, vida çapı, vida uzunluğu

1. INTRODUCTION AND PURPOSE

There are studies in the literature on the use of osseointegrated implants for orthodontic purposes. However, the use of these implants in orthodontics has been limited due to their long recovery periods and the need for two-stage surgery. Introduced by Kanomi for the first time, mini screws are frequently used in cases where the need for anchorage is critical, due to their advantages such as the large number of application areas in the field of orthodontics, ease of application and removal, immediate application of force and low cost (1,2). Mini screws do not need to be osseointegrated and their stability is provided by mechanical locking by being attached to the bone mechanically.

Due to their mechanical adhesion properties, mini screws should have a certain primary stability in order to be loaded with orthodontic force. Increasing the primary stability positively affects the success of mini screws (3). There are also studies reporting that the success of mini screws is lower than that of osseointegrated dental implants (4-7). Despite their advantages, the primary stability of orthodontic mini screws should be increased so that they do not have to be removed due to mobility that may occur before the application of force or in the middle of treatment. Primary stability can be achieved by increasing the length and diameter of the mini screws (8). However, since the mini screws are mostly placed between the roots due to their usage areas, there may be restrictions on diameter and length (9). Therefore, other ways are sought to increase the success of mini screws. It has been reported that if orthodontic force can be distributed over a wider area, mini screw stability (anchorage) and resistance to force will increase.

In another thesis study conducted in our faculty, it was proved that both stability and force resistance were significantly increased by increasing cortical bone support and the surface contact area of mini screws with the mini implant ring (MIR) appliance developed by Dr. Murat Tozlu (10). The purpose of the present study is to investigate the effect of MIR appliance on strength resistance and stabilization when used in vitro with mini screws of different lengths and diameters. It was aimed to determine the optimum usage method of the MIR appliance by placing mini screws of different lengths and diameters in bovine hip bones together with the MIR appliance and examining the application and extraction torque values as well as the resistance values against the force.

2. GENERAL INFORMATION

2.1. What is Skeletal Anchorage?

Anchorage systems which obtain support from bone are called skeletal anchorage and these systems were first used by Gainsforth and Higley at the University of Iowa in 1945 for orthodontic anchorage in intraosseous implants (11). Since then, skeletally supported devices such as plate screws, mini plates, wires and onplants have been developed. These emerging devices have become quite popular as they do not require direct patient cooperation.

2.1.1. History of Skeletal Anchorage

The first implant application was carried out at Harvard University in 1937. Branemark et al. introduced osseointegrated dental implants in 1969, and the independence of these screws, which remained stable against occlusal forces, began to attract the attention of orthodontists in search of solid anchorage (12). Implants for orthodontic anchorage was first used in the University of Iowa in 1945 (13). In a study they conducted in 1983, Creekmore and Eklund provided support from intraosseous screws placed at the lower level of the nasal cavity and stated that these screws could be used for skeletal anchorage (14). Later, Robert et al. used retromolar implants, and Wehrbein and Merz used palatal implants as anchorage (15,16). Block and Hoffman introduced orthodontic implants in 1995 (13).

The first mini implant specially designed for orthodontic applications was introduced by Kanomi in 1997 (18). Mini plates were developed with different designs later on, and case reports, for example, in relation to intrusion of the tooth or tooth group to which the plate was applied, in relation to severe Class II malocclusion as well as open bite correction have been reported in the literature (15, 17, 19, 20).

2.1.2. Skeletal Anchorage with Mini Screws

Mini screws do not need to be osseointegrated and their stability is due to mechanical locking. There is another version of the screws commonly used in oral and maxillofacial surgery and they are of different size and diameter. When the mini screw is compared to dental implants, it confers a number of advantages including easy applicability, cheapness, small size, extensive application area, and easy removal at the end of treatment (2).

2.1.3. Skeletal Anchorage with Mini Plate

Miniplates basically have the same features as the plates used in maxillofacial surgery. Umemori et al., and Jenner and Fitzpatrick were the first researchers to use bone plates in orthodontics (22,23). Miniplates were later developed with different designs such as the Bollard Mini Plate, the C-tube, the Surgitec Zygoma Anchor miniplate and the MPI (15, 19, 20, 24). One end of the orthodontic miniplate is screwed into the cortical bone, while the other end has attachments to which orthodontic forces can be applied. Intrusion of the tooth or tooth group, treatment of severe perplexity, severe class II malocclusion and open bite correction have been successfully achieved with the use of miniplates (17, 19, 21, 22).

2.1.4. Implants and Skeletal Anchorage

Implants have taken their place in clinical practice with the development of their use in prosthetic dentistry (25,26). However, although the clinical success rates of implants are higher compared to mini screws, they could not be used routinely in orthodontic use because they require two-stage surgery, their application area is limited, they require re-surgery when removal is required, and they are expensive (4-7).

2.2. To what extent have Mini Screw been successful?

In studies performed, the success rate of mini screws varied between 0% and 100%. However, the average success rate was found to be more than 80% (27-29). The first factor associated with this variability in success rate is mini screw mobility or displacement. In some studies, keeping the mini screw in usable condition was accepted as a success, while it was accepted as a failure in other studies. The second factor is related to the follow-up time. For example, if a mini screw fell out in the fourth month, it was considered successful for a study that evaluated the 3-month follow-up period, but was considered unsuccessful in a study evaluating patients with a follow-up period of more than 4 months. While the study design and methodological differences can be considered as the third factor, the deficiencies in the control of the variables affect the success rate (24).

2.3. Factors Affecting Mini Screw Success

2.3.1. Factors Related to the Mini Screw

2.3.1.1. Mini Screw Diameter

The contact mini screw surface area is directly related to cortical bone mini screw stability. As the diameter of the mini screw increases, the contact area increases and this directly affects the stability. Mini screw stability is directly proportional to the mini screw surface area in contact with cortical bone (10.30.31). The diameters of the screws used in mini screw studies generally vary between 1.0 and 2.3 mm. Success rates in studies show great variation (0-100%). In a study by Miyawaki et al., it was reported that the success rates of 1.5 and 2.3 mm diameter mini screws were the same and that they were significantly more successful than those of mini screws of 1.0 mm diameter (2). Likewise, in vitro studies on porcine iliac bone show that there is a statistically significant relationship between mini screw diameter and mini screw stability (32,33). The diameter of a screw is directly proportional to its resistance to breakage. Due to the risk of fracture during application of small diameter mini screws (44-46), mini screws with a diameter less than 1.3 mm should not be applied, especially in the lower jaw where the cortical bone is thick (34,35). Studies would indicate that mini screws of this diameter break (4,5).

However, titanium is a weaker material and more likely to fracture compared to stainless steel, and titanium mini screws with a diameter of 1.5 mm have a resistance of 40 N x cm. Since it may be possible to apply force that exceeds this resistance during application, screw diameter is important and a 0.2 mm reduction in the screw diameter results in a reduction of the resistance by half. Therefore, it is not recommended to use mini screws narrower than 1.5 mm (35).

In case excessive resistance is encountered during application, drilling a guide hole without continuing with the application would be a more appropriate option.

2.3.1.2. Mini screw Length

Studies have shown that the screw length does not affect the success of mini screws (2,7). Basically, the length of the mini screw to be applied is determined according to the thickness of the mucosa, application angle, proximity of adjacent structures, and bone quality (6, 37-39). Short screws applied in the palatal area can be lost due to thick mucosa (6, 40). Since the screw length in the bone may be insufficient in those areas where the mucosa is thick, it is recommended to use longer mini screws in this area (41,42). The mini screw basically takes its retention from cortical bone and in angled applications, the application depth inside the bone should be at least 5-6 mm to provide contact with the whole cortical bone (6,43,44). If the length of the mini screws is longer than 5 mm, their stability is not affected by their length (2). There are also studies in the literature indicating that mini screw length is effective on its own (4,6,10). In their in vitro study, Wilmes and Drescher concluded that the depth of application alone significantly increased the primary stability of the mini screw (45).

On the other hand, different results were shown in some studies. In the literature, the shortest screw applied so far was used in an animal study and was 3 mm. The success rates of the 3 mm and 6 mm length mini screws did not make a statistical difference when unusual situations were encountered with respect to the animals used in the study. However, the entire cortical bone had to be proceeded with mini screws of both lengths (40).

2.3.1.3. Thread Structure of a Mini Screw

Mini screw thread structures are varied and can have either symmetrical or asymmetrical sections. In a symmetrical section, the thread structures run symmetrically parallel to each other from screw tip to screw neck. However, while it provides convenience in application in the asymmetrical section starting with 45˚ from the screw tip and ending with 90˚ in length, it can also play a preventive role in terms of forces in the tensile direction (35).

The thread structure, number and the opening of a parallel groove along the screw can affect the stability between threads (46). The groove along the screw removes bone chips formed during screwing. It is seen that as the number and length of grooves increase, bone damage increases and application torque decreases (47). In contrast, another study reveals that the grooved structure of the mini screw increases both the application torque and the scraping-off resistance (48). The higher application torque of grooved screws has been associated with increased friction due to bone chips accumulating and becoming trapped between the threads (47, 48). Since the screwing process is done by hand in a non-continuous manner, bone chips can be placed in the screw groove between the turning movements. Therefore, it may be necessary to apply more force when turning again (49, 50). The increased friction at the screw-bone interface increases the resistance of the thread slopes against scraping-off (50).

Another feature of the mini screw thread structure is its depth. Screw-type implants with a deeper thread structure show better primary stability (51).

A double thread structure is used in mini screws. Mini screws with a double thread structure have two different thread structures symmetrical in themselves. With these properties, it has been reported that they show a higher extraction torque and better mechanical stability compared to those with normal thread structure (52).

2.3.1.4. Mini Screw Surface Properties

Mini screws have a threaded structure, and no roughening procedure is applied in the majority of those available in the market. However, although more expensive, mini-implants, whose surfaces are acidified and where metal parts are attached to these surfaces by heat and pressure (SLA), can also be used. In this study, the term ‘mini screw’ is used for those screws produced especially for orthodontics and whose surfaces are not treated. In contrast, the term ‘mini-implant’ is used for those produced for orthodontic purposes, whose surfaces are treated; the term ‘dental implant’ is employed for dental implants used for orthodontic purposes.

In a study comparing SLA-surfaced mini-implants with normal-surfaced mini screws, it was reported that those with an SLA surface had a higher removal torque than others and showed new bone formation around the screw (53). In addition, Lee et al. reported that SLA-surfaced mini screws show increased stability both in the early period and after osseointegration, and that various orthodontic forces can be applied with these mini screws (3). In terms of success criteria, some studies have shown that screw surface characteristics do not affect mini screw success in early loading (54,55).

It has been shown that better bone remodeling was obtained in surface-treated implants compared to threaded implants. Due to the surface properties of implants with treated surfaces, three-dimensional bone contact can be provided on the implant surface, and thus, SLA implants with shorter lengths can remain osseointegrated under orthodontic forces compared to those with a flat surface and those which are grooved (56).

2.3.1.5. Shape of the Screw

The shape of a mini screw can be conical or cylindrical. The diameter of a cylindrical screw is the same throughout the screw, except for a little section at the screw tip. However, there is an average difference of 0.3-0.4 mm between the thickest part and the thinnest part of the conical screw. Therefore, conical implants have 20-30% less surface area compared to cylindrical ones (57). This reduces the total surface area contact with the bone and can negatively affect stability for dental implants (8). However, in the case of mini screws, tighter cortical bone contact is obtained with the conical structure and better primary stability is provided (32,58). In addition, if the distance between the roots is between 2.5-3.5 mm, a conical screw should be preferred in order to reduce the risk of root damage by tapering (28,59).

In their animal study on the primary and secondary stability of mini screws, Cha et al. reported that conical mini screws showed better results in primary stability, but there was no difference between conical and cylindrical screws in terms of secondary stability. Considering the results under loading, while conical screws showed more MET in the 3rd

week, no MET difference was observed between the screws in the 12th week. Considering the time required for tooth or tooth-group movement, the cylindrical structure is not thought to result in a clinically significant disadvantage (60).

2.3.1.6. Material the Mini Screw is Made of

Thread diameter and depth, elasticity coefficient and elasticity limit are the determining factors in the mechanical success of screws (61). Although steel alloy screws are more resistant to fracture than those produced from titanium (28), the lower elasticity coefficient of the titanium alloy (being more flexible) and its better integration with living tissues provide a superior fixation opportunity. From a production standpoint, titanium alloy mini screws are therefore the preferred option (61,62).

2.3.2. Factors Related to Patients

2.3.2.1. Gender

When the gender factor, which is one of the patient-related factors, is examined, it is seen that most of the patients included in the studies were female patients (5, 30.37, 63). In a study by Özkalaycı et al. (2016) in relation to factors affecting the success of orthodontic mini screws, it was reported that 65.8% of the study group were female and 34.2% male. Considering the results obtained from the study in question, it has been reported that the remarkable relationship between the number of screws and gender may be due to the use of one screw per patient, the fact that all patients were female and the number of female patients was higher, or that female patients were more willing than men to correct relatively acceptable dental disorders such as midline deviation (64).

In a study of 141 patients, Lee et al. concluded that gender is not a determinant of mini-screw success (3). However, in another study using CT, it was found that the cortical bone in the attached gingiva located in the mesial of the upper first molar was thinner in females (65).

2.3.2.2. Age

In most studies conducted with mini screws, the age range of patients was seen to be quite wide. There is a general opinion that patient age is insignificant with respect to the success of mini screws. However, Chen et al. found in a retrospective study of 129 patients that patients under the age of 30 had a higher risk of failure compared to older patients (66). While primary stability is easily achieved in adults, mini screw failure rates are significantly higher in adolescents (67). This is because of cortical thickness and density, as well as higher levels of bone remodeling, which can compromise a mini screw in terms of both primary and secondary stability. Therefore, although mini screws are successful in adolescents, care is recommended and the loading force should be kept low (e.g. 50 g) during the first 6 weeks after insertion (68). As a result of their study on 141 patients in 2010, Lee et al. reported that factors such as insertion site, clinician difference, gender and oral hygiene did not make a statistically significant difference in mini-screw success rates. However, they drew attention to the early loss of mini screws placed in patients younger than 20 years of age and recommended greater levels of care with regard to these patients (3).

2.3.2.3. Systemic Diseases

Osteoporosis, uncontrolled diabetes, periodontal disease, smoking and drugs such as bisphosphonates are considered risk factors for classical dental implants (5, 69). For such patients, it is recognized that a longer recovery period is required in mini screw application, and case-specific loading protocols can be created (69). Alharbi et al. showed in their systematic review that smoking has a significant effect on mini screw loss (70).

Heavy smoking is associated with a significantly higher failure rate (71). Therefore, although smoking is not an absolute contraindication with regard to the use of mini screws, it is recommended that smokers be warned about the risk and that they stop smoking before placement of the mini screw (68).

2.3.3. Factors Related to Surgical Intervention

2.3.3.1. Flap Opening

Different results have been reported in studies comparing mini-screw application procedures with and without flap. While no significant difference has been noted with respect to success rates between the two applications in some studies (2,42), Kuroda et al. reported that the application without flap was more successful and that patients reported less pain and discomfort after application - 116 mini screws were applied in their study. (37).

2.3.3.2. Drilling a Guide Hole

When applying mini screws, it may be preferrentail to drill a guide hole. The guide hole drilled can be enough to either pierce only the cortical bone (6, 38) or extend to the length of the mini screw (30). While deciding this, consideration should be given to whether the mini screw is “self-tapping” or “self-drilling”. While “self-drilling” mini screws can be applied without drilling any guide holes or by drilling only the cortical section, for “self-tapping” screws, the guide hole should be opened to the full length of the screw. In cases where bone quality is low, it may be preferable to drill only the cortical part in a “self-tapping” application. In this case, it is necessary to apply vertical force with a hand screwdriver during the application (33).

If it is planned to drill a guide hole to pierce the cortical bone, a depth of 3 mm should be utilized to ensure that the entire cortical bone is drilled. The thickest cortical bone is located in the lower jaw “angular” region and is 3 mm (72). It may be preferential to drill the guide hole to a depth equivalent to the screw length (73,74). The guide hole depth in cancellous bone does not affect mini screw stability (32). However, there are publications that assert the opposite and say that tight contact of screw threads and cancellous bone will be achieved by not drilling a hole in the cancellous bone (75) and that this is effective in achieving stability (76,77). In addition, it has been shown that the screws applied without drilling the guide slot with the drilling router provide a tighter bone-screw relationship (78) and cause less bone chips and thermal damage (74,79).

If the mini screw drill is to be applied by opening the guide slot with the router, the diameter of the router should be narrower than the mini screw diameter. It is important that the diameter and depth of the guide hole prepared in terms of primary stability be less than the respective mini screw measurements (45). However, it has been reported that necrosis and local ischemia may occur in the bone around the mini screw as a result of stress caused by a guide hole, which is much narrower than the diameter of the mini screw (30.80).

In animal studies by Chen et al., it was reported that 1.3 mm diameter mini screws placed by preparing a 0.9 mm guide hole were less successful than those inserted without guide hole preparation (81). Furthermore, after a one-week recovery period, Kim and Chang observed that the results from the mini screw group without a guide hole were more successful than those from the guide-hole group (82). However, in their animal study, Heidemann et al. achieved 100% success in groups with and without guide holes in which no force was applied during the recovery period (74).

As a result of histological studies, it was observed that there was more contact between the bone with the mini screw applied without drilling the guide hole, and over time, more bone was formed around the mini screw (73,74, 81). This was explained by the fact that when the guide hole is not drilled, it is less traumatic, and tissue compliance is better (73). Success in mini screws applied without drilling a guide hole increases in direct proportion to the experience of the clinician (83,84).

Since an application without a guide hole may cause mini screw fractures because of the thick cortical bone in the lower and posterior regions of the lower jaw, the opening of a guide hole is recommended (81). In addition, any inflammation that may occur due to overheating while drilling may delay early healing (85). All these factors affect lower jaw mini screw success rates compared to those for the upper jaw (2,4,86).

2.3.3.3. Clinician's Experience

The atraumatic placement of the implant, which is the key to implant success, has been demonstrated by studies (28). Thermal damage, excessive surgical trauma, and osteonecrosis can cause the implant to be wrapped with a fibrous capsule (87).

2.3.3.4. Insertion Torque

Clinical studies conducted on mini screws revealed that insertion torque affects the success of the application of the mini screw (30.54, 63, 67). Motoyoshi et al. stated that the appropriate insertion torque for a 1.6 mm diameter mini screw should be between 5-10 Ncm and higher torque values negatively affect the success of a mini screw (30). In another study examining insertion torque and age factor, a higher success rate was found in the young adult group with early loading with an application torque of 5-10 Ncm in the upper jaw compared to the other groups (67). In another study where normal surfaced mini screws with different diameters between 1.4-2.0 mm and mini implants with an SLA surface were used, it was concluded that a torque application above 15 Ncm was required for mini screw success (64). In another study, it was argued that an 8-10 Ncm application torque was ideal and more or less intensive applications decrease the success rate (63). When Chen et al. applied 1.3 mm diameter screws by preparing guide holes (upper jaw mean value 3.5 Ncm, and lower jaw mean value 7.4 Ncm), they recorded less insertion torque compared to those they applied without preparing a guide hole (upper jaw mean value 5.6 Ncm, lower jaw mean value 8.7 Ncm) (81). Schon et al. observed similar results in their patients (88). Mini screw breaks occur at application torques of 23 Ncm and above. Therefore, the mini screw application torque should not exceed 20 Ncm (33).

Extraction torques of implants and mini screws were also analyzed in many studies. It was revealed that the results of histomorphometric examination of the implant surface and bone contact and extraction torque values were equivalent to each other (81). As the contact area of the implant surface with the bone increases, the removal torque values also increase.

2.3.3.5. Application Angle

Mini screws can be placed at different angles to increase the support taken from the cortical bone and to prevent biological damage to biological formations such as tooth roots, nerves, and veins (5, 67). To reduce the risk of root contact, it was suggested that mini screws should be applied at an angle of 30˚-40˚ with the long axis of the tooth in the posterior region of the upper jaw and at an angle of 10˚-20˚ in the posterior region of the lower jaw (89). A study by Kim et al. (2009) suggested that mini screws should be placed 2-4 mm away from the enamel-cementum border and at an angle of less than 45˚ with the long axis of the tooth for secure insertion of mini screws in the posterior region of the upper jaw (90). In a study by Park et al. (2010), mesiodistal angulation was examined in mini screw application. It was recommended that the mini screw be angled 10˚-20˚ distally and applied 0.5–2.7 mm further distal to the contact point (91).

2.3.3.6. Monocortical-bicortical Application

Mini screws are mostly applied monocortically due to their ease of application. On the other hand, some studies have shown that bicortical application increases the resistance of the mini screw against forces (92.93). In addition to these studies, in a case report in which the extraction gap was closed by moving the lower jaw molar teeth forward, the applied orthodontic force could be adjusted to pass the resistance center of the tooth or tooth group to be moved, thanks to the bicortically applied mini screw. This particular report served to highlight the advantages of bicortical application (94).

2.3.4. Anatomic Local Factors

Local factors affecting mini screw success are cortical bone thickness (CBT) and cortical bone quality, cancellous bone structure, insertion site, soft tissue features and the proximity of the mini screw to adjacent organs. CBT and inter-root distance measurements in the areas where the mini screws were placed were made by incision in the cadaver bones (86), three-dimensional images were taken from the patients (9,52, 57, 67,82, 87), and three-dimensional images were taken from the cadaver upper and lower jaws (86, 88-90). Soft tissue thicknesses were evaluated using an ultrasonic device (91).

2.3.4.1. Cortical Bone Thickness (CBT)

Cortical bone thickness (CBT) varies in many areas of the jaw. Generally, the CBT in the lower jaw buccal area is larger than that in the upper jaw. While CBT gradually increases from anterior to posterior in the lower jaw, it is thicker in the area between the premolar region in the upper jaw compared to the molar region (95).

Bone quality and quantity in the region where they are placed determine the load carrying capacity of mini screws (32,33,96,97). Better primary stability is obtained in thicker cortical bone (33). However, the risk of overheating has been reported during the placement of implants in the area with high cortex density (5,7). Motoyoshi et al. reported that mini screw success rates increase when CBT is more than 1mm (63).

2.3.4.2. Bone Density

In studies on primary stability, a highly intense analysis was performed on the effect of bone density on mini screw stability (58, 98.99). A direct proportion between bone density and stability was reported in these studies.

In their animal study, Cha et al. revealed that cortical bone density, screw shape and location were effective in stability. It was reported that low bone density and a cortical bone thickness of less than 0.5 mm were inversely proportional to mini screw success. However, low trabecular bone density and thin cortical bone were shown to increase the risk of microfracture development (67,99).

Although primary stability is better achieved in thicker and denser bones, some friction heat is generated during the insertion of the screws into the dense cortex and necrosis may develop when the temperature rises above 47^0C. It is recommended that irrigation be undertaken with saline solution and that worn drills not be used in order to prevent heat generation (100).

In a study they conducted with screws applied to osteoporotic bones, Battula et al. reported higher rupture resistance in normal bones compared to that in osteoporotic bones (101). In another similar study, a significant positive correlation was found between insertion torque and bone density. It was observed that as the bone density increased, the insertion torque also increased (102).

2.3.4.3. Insertion Area

Choosing the appropriate insertion area is the most important factor for the success of mini screws (7, 43, 34, 41,103-105). Mini screw success rates in the upper jaw are higher compared to those in the lower jaw (7,37,106). Although the cortical bone quality and quantity were better, the higher failure in the lower jaw was attributed to excessive stress during screw insertion, overheating when opening the guide hole, a short adherent gingival band, and hygiene problems (7, 37).

When the lower jaw was evaluated in general, more success was achieved with mini screws placed in the lower jaw premolar region in adult patients compared to those placed in the molar region (42). In addition, in some studies, proximity to the adjacent tooth root in the area where the mini screw was placed was identified as a risk factor for mini screw failure (107,108). However, wisdom teeth, grinding teeth, periodontal diseases, and edentulous areas are considered factors that can alter bone quality (109-111).

In an evaluation of right and left-side success rates, in a study by Kim et al., it was reported that there was no difference between the right and left regions with respect to the success of the mini screws placed between the second premolar and the first molar in the upper jaw (3).

2.3.4.4. Gingiva

Studies in the literature reveal that there is a relationship between mini screw success and soft tissue (5,7,54). Insertion of mini screws in the keratinized gingiva is recommended in many studies (7,38, 112). It has been reported that the formation and inflammation of hypertrophic tissue may be less in mini screws placed in the keratinized gingiva (39,110). If the mini screw is placed in the movable mucosa, the solution may be to cover the mini screw heads with mucosa to prevent hypertrophic tissue formation and inflammation (5,110).

In a study in which mucosal thicknesses were evaluated ultrasonically in male and female patients, it was reported that the thickness of the attached gingiva in the upper jaw buccal region of females was less than that of males, however, the gingival thickness in the lower buccal region and palatal chewing areas was not related to gender (117).

2.3.4.5. Proximity to Adjacent Organs and Root Damage

The stability of mini screws is adversely affected by proximity and contact with adjacent roots (107,108, 113-115). Inadequate bone structure, contact with the screw, and minor movements of the tooth roots under occlusal forces adversely affect mini screw stability (118). Resorption occurs as a result of the contact of the tooth root with the mini screw in the cement and dentin layers, and secondary cement repair may be required in this case (113-115).

In addition, if there is no severe damage, little clinical side effects can be expected due to the healing potential of surrounding tissues (113). The occurrence of excessive application torque or any sudden increase during application can be a sign of contact to the root (108).

2.3.5. Factors Related to Mini Screw Loading

2.3.5.1. Timing of Mini Screw Loading

There are different approaches in orthodontics in terms of mini screw loading time and terminology (2,5,37,67,69 105, 116). The mini screws used are evaluated in two different ways - early loading and late loading - in terms of the time between application and loading. In the early loading protocol, force is applied to the mini screw immediately after insertion or within 4 weeks, while in late loading, this time is at least 4 weeks after insertion.

In studies comparing the results, there is conflicting information about the time and terminology of mini screw loading (2,5,37,67,69,105,116). In some studies, early loading has been reported to increase success. In an animal study by Chen et al., it was reported that immediate loading did not affect the osseointegration of the mini screw, on the contrary, it increased bone adaptation (117). However, it was emphasized that there is a risk of movement as a result of loading the mini screw and therefore it should be located at a sufficient distance from important tissues. In another study by Woods et al., it was shown that the time of application of force and the application site of the mini screw did not affect bone-mini screw contact. Another result of the study in question was that immediate loading was reported to be more beneficial for bone-mini screw contact, since only mini screws that were not loaded in the control group showed mobility (118). In a study by Serra et al., histologically more bone deposition and better bone healing were reported in early loaded mini screws (119). It is seen that bone healing consists of four phases: healing, acceleration, active resorption, and waiting and formation phases. These phases last 17 weeks in total. The “acceleration phase” lasts for a few hours or a few days, followed by the “active resorption” phase, which will last for 2 weeks. During the waiting phase, osteoclasts are replaced by osteoblasts and this phase lasts for 1-2 weeks. In the formation phase, which is the last phase, all resorption areas in the bone are filled slowly for 13 weeks and the healing process is completed. The active resorption phase during bone healing is seen as critical, and it is important to work with light forces in early loading to be performed during this period (120). Although different opinions have been presented, mini screws with early loading can be considered mechanically stable in areas where bone quality is particularly poor, provided that the force does not exceed 50N in instant loading (38,69,121). In their study, Motoyoshi et al. found that mini screw success was higher in early-loaded mini screws compared to late-loaded ones in adults, however, they reported that there was no difference in mini screw success between the early-loaded group and the late-loaded group in young adults (67).

2.3.5.2. Magnitude of Orthodontic Force Applied

The different forces applied to the implants and the reaction of these forces in the bone surrounding the implant have been investigated in various animal studies (122,123). Besides the structural properties of the bone, the magnitude of force applied affects the remodeling of a bone (123). In clinical studies, the orthodontic forces applied on the mini screw vary between 50 gr - 400 gr, and it has been reported that 200 gr or less force be applied.

In a study by Wehrbein et al., it was observed that additional bone structure did not develop as a result of a 1 N force applied to the palatal bones of dogs, but when this force was increased to 2 N, significant bone formation was observed compared to that in the control group (123). Melsen and Lang stated that there was more bone remodeling in the force-applied group than in the control group (124). In these studies, it was seen that the subperiosteal new bone formed in a certain force range was in the area where the implants pressed on the bone (122,123).

Screw loss due to the extreme stresses that can develop around the mini screw can occur even under optimal forces (125). Because of the possible displacement of the screws with early loading and excessive force, it is recommended to start with a force of 50 g and to increase the force gradually (54, 110.125,126). Apart from increasing the force, another reason for screw displacement is related to the duration of the load. In a study by Wang and Liou, screw displacement was attributed to the duration of the load, not the magnitude or direction of the applied force. However, as a result of this study, the use of excessive force was still not recommended, and it was reported that applying more force than the force values used may cause other unknown results and further studies should be carried out on these subjects (127). Contrary to all these findings, there are studies reporting that the displacement of mini screws can also be seen at lower forces (109,128).

2.3.5.3. Duration of Orthodontic Force Applied

The time interval evaluated in studies on stability varies between 3-37 months, and the time interval of success in most studies is evaluated within a certain range such as 150 days, 180 days, 8 months, and 9 months (52, 64, 115, 126).

It was demonstrated in three separate studies that orthodontic force-applied screws were displaced, even if they did not fail over time (120, 126,128). In a study by Wang and Liou carried out on 32 female patients, the mini screws were loaded 2 weeks after their insertion, and cephalometric radiographs taken before loading and 5 months after loading showed that the mini screws moved under force. However, a significant relationship was found between the duration of force application and the amount of displacement. It was also stated that the amount of displacement may increase with increasing force (127). Moon et al. reported that failed mini screws usually fail 1-2 months after application, and over 90% of failures developed before 4 months.

2.3.5.4. Direction of Orthodontic Force Applied

Mini screws can be inserted in many places in the mouth. Therefore, the directions of the forces acting on the mini screw may differ. There are many studies in the literature that evaluate the relationship between the success of the implant and the direction in which the force is applied (7,38,39,43, 94). Costa et al. stated that turning force in the direction of mini screw removal can result in loss of the mini screw. (43) Cheng et al. suggested avoiding lateral, torsional and extrusive forces (7). In another study by Kim et al., it was demonstrated that SLA-surfaced mini screws resist counterclockwise rotational forces (129).

Freudenthaler et al. also suggested that the position for inserting the mini screw should be the same as the center of resistance of the thread (94). Similarly, the results of the pull-off test performed on the lower jaws of cadavers revealed that the resistance against failing increases as the direction of the applied force approaches the long axis of the mini screw. It was shown that the highest resistance occured when pulling the mini screws placed perpendicular to the bone along their own axes (130.131).

2.3.5. Other Factors Affecting the Success of Mini Screws

2.3.5.1. Orthodontic Indication

In a study by Kuroda et al., examining the effect of orthodontic movement type of mini-screws applied for different orthodontic indications on the success of the mini-screw, a higher rate of failure was detected during intrusion movements compared to those of retraction and protraction (37).

2.3.5.2. Maintenance of Mini Screws

Prophylactic antibiotics, chlorhexidine mouthwash, and oral hygiene education and supplementation are important factors in the maintenance of mini screws (37-39,63,67,110) and include the control of peri-implantitis. Park et al. reported that success was correlated with peri-implantitis control, but could not find a correlation between oral hygiene measures and mini screw success. They also reported higher success rates in the left side of the mouth (5). This result indicates that oral hygiene is better provided in right-handed patients (132).

2.3.5.3. Mobility of Mini Screws

Studies on mobility have shown that micro-movements of more than 100 microns can adversely affect healing and cause fibrous encapsulation (133,134).
Park et al. recommended that implant mobility and orthodontic forces be monitored regularly and stated that removable screws could be successful if applied forces were less than 200 grams (5). In some studies on mobility, it was shown that strength variables including occlusion and tongue movements as well as orthodontic strength factors could affect results (103,112, 135).

2.4. Primary Stability

Primary stability is defined as the stability of implants immediately after application. High primary stability is critically important for success in both mini screw and dental implant applications. Therefore, various methods have been tried to evaluate primary stability. Maximum application and extraction torque measurements, loading tests, and resonance frequency analysis are considered reliable methods for evaluating primary stability (33, 136-137). Adequate primary stability obtained with mini screws and application torque is important (15,22,53, 75). The same is true for dental implants (124,126). Primary stability factors include screw design, bone quality, mini screw site preparation, the absence of a guide hole or its depth and diameter if opened, and the angle of application (32, 139). In addition to histological evaluations, percussion tests, radiological examination and measurements made with the periotest device were also used in the primary stability measurement (60.73). However, the adequacy of these methods in diagnosis remains controversial (46,140.141). Although the periotest device is designed to measure dental mobility, it is also used in implant stability measurement. The application torque measurement, extraction torque measurement and Ostell's Resonance Frequency Analysis (RFA) used in primary stability measurement are more reliable methods. (142-144)

2.5. Can Mini Screws be Osseointegrated?

Osseointegration is not expected in mini screws. However, over time, it was reported that the bone and screw surface area increased (75) and there was a denser bone structure adjacent to those areas of increased bone destruction and construction around the screw (145,146). Similarly, with implant studies, it was shown that the density of the bone around the implant, which was exposed to pressure under orthodontic forces, increased and that the reconstruction activity of the bone accelerated (123, 124, 147, 148). An animal study by Büchter et al. revealed that the amount of bone surrounding the mini screw was higher in the 12th week compared to the 1st and 4th weeks after the application and immediate loading accelerated bone deposition and healing. It was reported that SLA-surfaced mini screws showed increased osseointegration immediately after application compared to those with normal surfaces (149). It was stated that at the end of the treatment, the SLA-surfaced mini screws could be easily removed without any complications (145). Although many studies reported increased osseointegration with SLA-surfaced mini screws, it was reported that surface characteristics did not affect the success rate clinically (54). In addition, Kim et al. reported that partial osseointegration, which could resist biomechanical forces, might occur without the surface properties being affected if sufficient recovery time is expected (129).

2.6. Studies on Primary Stability and Force Resistance

Force resistance measurement is also used in orthopedics, neurosurgery, plastic surgery, and maxillofacial surgery. It is another method frequently used to evaluate the biomechanical performance of screws used in orthodontics (97). Although force can be applied immediately after the application, their easy removal after treatment is an important advantage of mini screws in clinical use. Unlike dental implants, the mini screws that provide such an advantage are not expected to be osseointegrated.

In addition to the ability to apply force immediately after application, one of the most important advantages of mini screws that provide clinical usability is that they can be easily removed after treatment. This is because mini screws are not expected to be osseointegrated unlike dental implants. Since they are not osseointegrated, the stability and anchorage potential of mini screws are directly affected by how much mechanical locking they make with the bone immediately after application (primary stability) and how much support they can provide from the bone (anchorage). Especially in recent years, maximum application torque (MAT) (10.30.32,33, 45,47,54, 63) maximum extraction torque (MET) (55, 145), both MAT and MET (52, 60, 129), and force resistance (FR) (92.93) values were measured for primary stability and anchorage evaluation.

2.6.1. Studies Measuring the Maximum Application Torque (MAT)

Application torque tests are used to determine the primary stability of the shape and surface properties of a screw. MAT is an important factor used in determining the bonding strength of screw-type implants in bone (153).

In studies evaluating the relationship between the success of mini screws and mini implants with MAT, it has been reported that the thread structure, diameter, length and application angle of the mini screw, application depth, diameter of the guide hole to be drilled and the depth of the guide hole affect the maximum application torque (10.33,47,140). In addition, despite these results (150), there are publications reporting that CBT is effective on MAT (10.33,63).

In an in vitro study conducted by CBT to test the effect of mini screw design, diameter, guide hole depth and diameter on mini screw stability, Wilmes et al. applied 5 different mini screws to pig hip bones after drilling guide holes of different diameters and depths. The measured MAT values were 9.12 Ncm and 8.9 Ncm for 1.6 x 10 mm and 1.6 x 8 mm mini screws with a conical structure. The values recorded for cylindrical structures were 1.6 x 10 mm-2.92 Ncm and 1.6 x 8 mm - 2.48 Ncm. As a result of this study, it was reported that the 5 parameters tested were effective on mini screw stability (33).

In a study by Motoyoshi et al. conducted with 41 patients, 124 conical mini screws (1.6 x 8.0 mm) were applied using a torque screwdriver after preparing a guide hole with a diameter of 1.3 mm and a depth of 8 mm, the effect of the MAT value on the success of the mini screw was tested and the clinical success rate was reported as 85.5% (30). The application of orthodontic force to the mini screw for at least 6 months and with an average MAT value varying between 7.2 and 13.5 Ncm according to the area of insertion were reported as success criteria. Researchers suggested that screws 1.6mm in diameter should be applied with a MAT of between 5-10 Ncm in order to increase the clinical success rate. However, in another clinical trial by Motoyoshi et al., the effect of CBT and MAT on mini screw stability was evaluated and 1.6 x 8.0 mm mini screws were considered successful if they did not result in pain or clinical mobility over a 6-month period. The success rate in the study was reported as 87.4%. CBT was significantly higher in the clinically successful group. In terms of application torque, it was reported that an application torque of 8-10 Ncm significantly increased rates of success. As a result, CBT should be at least 1 mm in the area where the mini screw is applied, and the application torque should not exceed 10 Ncm (63). In an in vitro study, Wilmes et al. applied 7 different brands and 13 different types of mini screws to pig hip bone to measure the MAT value and tested the effect of mini screw design on primary stability. The guide hole was drilled to a hole depth of 3 mm using a 1.1 mm drill for mini screws of 1.6 mm and narrower, and a 1.3 mm drill for mini screws larger than 1.6 mm. MAT values recorded were between 1 and 48 Ncm. It was explained that mini screw diameter and design had a significant effect on primary stability and that conical mini screws showed better primary stability compared to cylindrical ones (32).

In another in vitro study, however, Wilmes et al., put 2 different mini screws (1.6 x 8 mm and 2.0 x 10 mm) into pig hipbone using 7 different angles (30˚, 40˚, 50˚, 60˚, 70˚, 80˚, 90˚) and assessed the primary stability by measuring the MAT value. A guide hole of 1.3 mm was drilled for 1.6 mm diameter mini screws and for 1.0 mm and 2.0 mm diameter same brand screws. The mini screws were initially tightened using a hand screwdriver until a distance of 0.7 mm was left between the bone surface and the mini screw neck. Then, 0.2 mm of it was tightened with a robot machine with torque and angle sensor added and the MAT values were measured. A distance of 0.5 mm between the bone surface and the mini screw neck was left as the clinical gingival thickness. For a 1.6 mm diameter mini screw, with an application of 90˚, MAT was measured as approximately 9 Ncm. According to the results of this study, the highest MAT value and therefore the best primary stability were obtained with an angle of 60˚-70˚(140).

Unlike other studies, in a study by Salmoria et al., 60 mini screws (1.6 x 6.0 mm in size) were applied to the mandibles of dogs by measuring their MAT values, and the mini screws were applied on the 15th and 60th days after the application. The measured mean MAT value and cortical bone thickness were 24.5 Ncm and 2.6 mm, respectively. As a result of the study, it was suggested that there was no correlation between the application torque and scraping off, that application torque measurement could not be used to predict the holding strength of the mini screw in the bone, and that there was no correlation between application torque and CBT (150).

Lim et al., who applied mini screws of different diameters and lengths artificial bones with different cortical thicknesses, tested the effect of the three variables used on the MAT value and therefore on primary stability. MAT values for 1.5 x 8.0 mm conical and cylindrical mini screws in cortical bone with different thicknesses were recorded as 1.0 mm- 20.50 Ncm for cylindrical, 1.5 mm - 20.91 Ncm, 2.0 mm - 22, 14 Ncm, 1.0 mm - 30.68 Ncm, 1.5 mm - 37.27 Ncm, and 2.0 mm - 39.38 Ncm for the conical screws. As a result of this study, it was reported that mini screw length, diameter and CBT were effective with respect to the primary stability of the mini screw (31).

In another study, Chaddad et al. set the torque screwdriver to a value of 15 Ncm and evaluated the application torque values at either above or below 15 Ncm. They loaded normal surfaced and SLA-surfaced mini screws early at different times. As a result of the study, it was stated that mini screw surface features did not affect mini screw success, but that a torque value over 15 Ncm was critical for mini screw success (54).

By evaluating the effect of application depth and guide hole diameter on mini screw stability, Wilmes and Drescher conducted an in vitro test for testing - they drilled guide holes of 3 mm deep and of different diameters (1.0 mm, 1.1 mm, 1.2 mm, and 1.3 mm) in pig hipbone, 1.6 x 10 mm mini screws of different depths (7.5mm, 8.5mm, and 9.5mm). While the MAT values measured for 7.5 mm, 8.5 mm, and 9.5 mm application depths were 5.16 Ncm, 6.55 Ncm, and 9.44 Ncm respectively, the MAT values recorded for the guide hole diameters of 1.0 mm, 1.1 mm, 1,2 mm, 1.3 mm were 8.35 Ncm, 7.75 Ncm, 6.17 Ncm, and 5.31 Ncm respectively. The researchers concluded that both variables significantly affected mini screw primary stability (45).

In a study by Brinley et al., a total of 90 mini screws of 6 mm length, and 1.6 mm and 1.8 mm in diameter were placed in artificial and cadaver bones. MAT and scraping force values were measured to investigate the effects of groove structure and groove slope on primary stability. In order to test the effect of the thread slope, mini screws with a distance between threads of 1.0 mm were compared with screws with inter- thread distances of 0.75 mm and 1.25 mm in the control group and the test group respectively. MAT values were recorded as 9.05 Ncm, 8.45 Ncm and 8.15 Ncm in artificial bone and 15.2 Ncm, 13.6 Ncm and 12,6 Ncm in cadaver bone, respectively, for thread distances of 0.75 mm, 1.0 mm, and 1.25 mm. As a result of this study, it was reported that the corrugated structure increased application torque and resistance to scraping- off, the application torque increased as the distance between the threads decreased, but remained below the significance level, and there was a positive correlation between the application torque and scraping- off resistance (47).

2.6.2. Studies Measuring the Maximum Extraction Torque (MET)

MAT and MET measurements are used to test the primary stability of threaded implants such as mini screws under the influence of mechanical properties. Extraction torque measurements test the biomechanical condition at the implant-bone interface (136).
In the literature, among the studies evaluating the stability of mini screws, there are studies that measure MAT and MET values together, as well as studies that measure only MAT or only MET values. In studies that measure only MET, the recovery time and safe removal of mini implants before loading were tested (145).

In a study they carried out by applying 64 mini implants with a diameter of 1.8 mm and a length of 8.5 mm in 37 patients, Kim et al. reported that SLA mini implants could be reliably removed. In a continuation of the study, the force was applied for an average of 14.8 days in the 4th month of recovery and the average MET value was reported as 16.4 Ncm. The study emphasized that SLA mini implants can be reliably removed at the end of treatment, but the time to be loaded before disassembly should not exceed 6 months (145). In their animal study, Wu et al. determined the biomechanical resistances at 0, 1, 2, 4, and 8 weeks later in non-force mini screws by measuring the MET and scraping-off force values, and of 90 mini screws with a diameter of 1.9 mm and a length of 6.0 mm. The screw was applied under anesthesia to the shin bones of New Zealand white rabbits by drilling a guide hole. Of these mini screws, 60 were used in the MET test and 30 in the scraping-off test. In the extraction test performed immediately after application, the MET value was above 20 Ncm. In their study, the researchers determined that there was an increase in MET and scraping-off force values over time. They stated that mini-screw healing is an uninterrupted process from time of application. However, they considered the 4-week recovery as a critical period in this process and did not recommend applying force earlier (151).

In their study on rabbits using SLA and normal surface 1.8 x 9.5 mm mini screws, Mo et al. assessed early loading at different periods (0^{th}, 1^{st} and 3rd days, and 1^{st}, 6^{th} and 10^{th} weeks) on mini screw success and its effect on MET. They reported that loading at any time within the 10-week period did not affect the success rate, and that SLA mini implants had a higher MET value than those with normal surfaces over the 6-week healing period (55).

2.6.3. Studies Measuring both MAT and MET

In studies measuring both MAT and MET values, the effect of mini screw shape on primary and secondary stability (60), the effects of the thread structure on application and removal times as well as application and removal torque values, the resistance of mini screws to rotational forces under surface properties (129), and the effect of screw shape, and different cortical bone thicknesses on stability (152) were tested (52).

In their animal study using SLA-surfaced and normal-surfaced mini screws, Kim et al. applied rotational force to a total of 96 mini screws of 1.8 mm diameter and 8.5 mm length in order to test the stability and resistance to rotational force of the mini screws. After a three-week recovery period, 150 g of rotational force was applied, and the mini screws were removed at the 8^{th} week. Measured MAT value for normal-surface mini screws was recorded as 19.25 Ncm and the MET value as 6.18 Ncm. The measured MAT value of SLA-surfaced screws was recorded as 15.27 Ncm and the MET value as 8.43 Ncm. As a result of this study, it was stated that SLA-surfaced mini screws could resist counterclockwise rotational forces and SLA-surfaced mini screws showed increased osseointegration shortly after application compared to normal mini screws. It was also reported that mini screws could be partially osseointegrated if healing time was sufficient (129).

In another animal study, Cha et al. applied a total of 48 conical and cylindrical mini screws, 1.5 x 7.0 mm in size, to dog mandibles, and using a torque device, they evaluated the primary and secondary stability of both types of mini screws by measuring the MET values at the 3rd and 12th weeks after loading. A statistically significant difference was found between MAT and MET values in the 3rd week (MAT: cylindrical: 13.6 Ncm: conical: 22.3 Ncn: and MET: cylindrical: 5.7 Ncm, and conical: 9.1 Ncm). Interestingly, in the 12th week, a higher MET value was reported for cylindrical screws. However, the difference found was not statistically significant (12th week MET: cylindrical: 4.2 Ncm, and conical: 3.0 Ncm). As a result of this study, it was reported that conical mini screws showed better primary stability than cylindrical ones and there was no difference between screws in terms of secondary stability (60).

Song et al. applied 3 different types of mini screws (1.6 x 8.0 mm cylindrical, and 2.0 x 7.0 mm and 1.5 x 7.0 mm conical) to artificial bones of different cortical thicknesses (0 mm, 1 mm, 2 mm, and 3 mm) using a torque tester to test the effect of CBT on MAT and MET values. It was reported that the MAT and MET values of the mini screws with a cylindrical structure with a diameter of 1.6 mm were not affected by the increase in CBT. and that the MAT and MET values of the other mini screws with conical structure increased significantly as the CBT increased (152).

In an in vitro study conducted to test the mechanical effects of cylindrical, conical, and double threaded structures, Kim et al. applied mini screws 1.6 mm in diameter, and 6 mm, and 8 mm in length on artificial bone using a torque measuring device. In addition to the MAT and MET values, they measured the application and extraction times and moments. As a result of the study, it was stated that while the application torque reached the maximum value in the double grooved group, there was a more moderate increase compared to the other groups, and this could minimize the stress on the bone. It was also noted that while the double thread group did not have the highest MAT value, the MET value was best. This was accepted as an advantage by the researchers. However, it was emphasized that double-threaded mini screws required further investigation in terms of stress that might occur in the bone, since they had a lower MAT value, but required a longer application time (52).

2.6.4. Studies Measuring the Force Resistance (FR)

In studies measuring force resistance, the effect of mini screws with the same diameter or different diameters on force resistance was tested in monocortical and bicortical applications (92,93). Brettin et al. measured the force resistance by applying a total of 44 mini screws bicortically and monocortically in cadavers and reported that bicortical application revealed more force resistance, that as buccal bone thickness increased in the lower jaw, the resulting force resistance in the monocortical applied mini screws increased, that a buccal bone thickness increase in the upper jaw did not affect strength resistance for monocortical applications and after strength testing for both jaws that the monocortically applied mini screws showed greater mobility than those applied bicortically (93).

In their study they applied a total of 96 2.5 x 17 mm and 1.5 x 15 mm mini screws monocortically and bicortically to cadaver bones, Morarend et al. applied force perpendicular to the long axis of the mini screw and measured the force resistances until the screw head was displaced 0.6 mm. After the force test, all mini screws were removed, bone segments were cut, and bone measurements were made. In this study, it was reported that larger diameter mini screws showed greater force resistance in both upper and lower jaws, smaller diameter bicortical mini screws had at least equal force resistance to that in larger diameter monocortical examples, and apical-coronal or right-left applications did not affect force resistance (92).

In a doctoral dissertation conducted by Tozlu. in 2010, the effect of the mini implant ring apparatus on the initial stability and force resistance of the mini screw in an in-vitro environment was evaluated and 48 mini screws were applied. The mini screws were divided into 2 separate groups, each of which consisted of 24 mini screws. The MIR apparatus was applied to the mini screws in the test group, and the other group without MIR was evaluated as the control group. The mini screws in the study were applied to samples obtained from bovine hip bones and the maximum insertion torque values of all mini screws were measured with a torque meter screwdriver. Then, force was applied perpendicular to the long axis of the mini screw with an Instron tester, and their strength and resistance values were recorded until the mini screws were displaced 0.6 mm. After evaluating the mobility of the force-tested mini screws, the mini screws were removed from the bone by measuring the MET values with a torque meter screwdriver. Finally, the bone segments were divided in two such that the incision line passed through the screw sockets, and cortical bone thicknesses were then measured. According to the results obtained, the test and control groups were divided into 2 subgroups, thin and thick, according to their cortical bone thickness. According to the findings of the study, the mean MYT and MET values obtained in the thin cortical bone group without MIR were 8.71 ± 3.29 Ncm and 4.55 ± 3.26 Ncm, respectively. The mean MYT and MET values obtained in the thick cortical bone group (CBT: 1.66 mm) without MIR were 14.8 ± 2.8 Ncm and 9.89 ± 4 Ncm, respectively. The mean MRT and MET values obtained in the thin cortical bone group (CBT: 0.80 mm) applied with MIR were 12.43 ± 4.41 Ncm and 5.81 ± 3.28 Ncm, respectively. The mean MYT and MET values obtained in the thick cortical bone group (CBT: 1.64 mm) in which MIR was applied were 18.17 ± 1.27 Ncm and 10.93 ± 4.93 Ncm, respectively. As a result of this study, it was stated that the MYT and FR values of the group in which the MIR was applied were significantly higher compared to those in the group without MIR. It was stated that the significant increase in the strength resistance and anchorage values of MIR-applied mini screws was more distinct in the presence of thinner cortical bone. As a result, it was reported that the MIR apparatus increased the force resistance and anchorage values of the mini screws and caused a significant increase in the insertion torques and initial stability of the mini screws (10).

3. MATERIALS and METHODS

3.1. Equipment Related to the Force Test

3.1.1. Mini Screw

A total of 120 TM (Trimed, Ankara, Turkey) mini screws, including 20 pieces of 1.4 mm diameter and 6 mm length, 20 pieces of 1.4 mm diameter and 8 mm length, 20 pieces of 1.6 mm diameter and 6 mm length, 20 pieces of 1.6 mm diameter of and 8 mm length, 20 pieces of 1.8 mm diameter and 6 mm length, and 20 pieces of 1.8 mm diameter and 8 mm length were used in the present study (Photo 3.1.). Conical TM mini screws were preferred in the study. TM mini screws were “self-drilling” and were made of titanium.

3.1.2. MIR

A total of 60 MIRs were used in the test group (Photo 3.2.). The MIR had an outer diameter of 5 mm and an inner diameter of 2 mm. There were 4 sharp protrusions in the area in contact with the cortical bone. These protrusions had a length of 0.75 mm (Figure 3.1.). The MIR’s were made of titanium. The housing section of the MIR was designed to adapt to the neck of the TM mini screw. The application of the MIR appliance is schematized in (Figure 3.2.).

3.1.3 Bone Model

Bovine hip bone was used in the present study (Photo 3.3.). The CBT in the iliosacral joint, which has values compatible with the human upper jaw and lower jaw CBT, varies between 0.5 mm – 1 mm, and the CBT in the hip joint varies between 2.0 mm – 3.0 mm (9,66,153,154). Fresh bones were procured from reliable meat and meat product companies that offer certified products using animals without any disease. The parts to be used were cut off from the main bone. The bones were kept in a sealed bag with moist fabrics until the completion of the experiment and frozen at -5 ° C. It was reported that the freezing process did not adversely affect the elastic properties of the bone (155).

Photo 3.1. TM mini screw

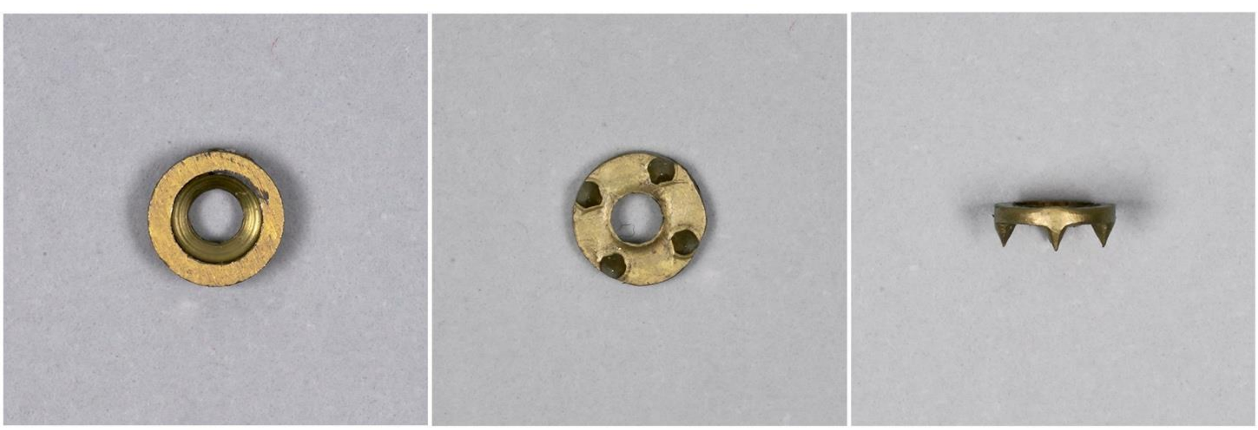


Photo 3.2. MIR appliance

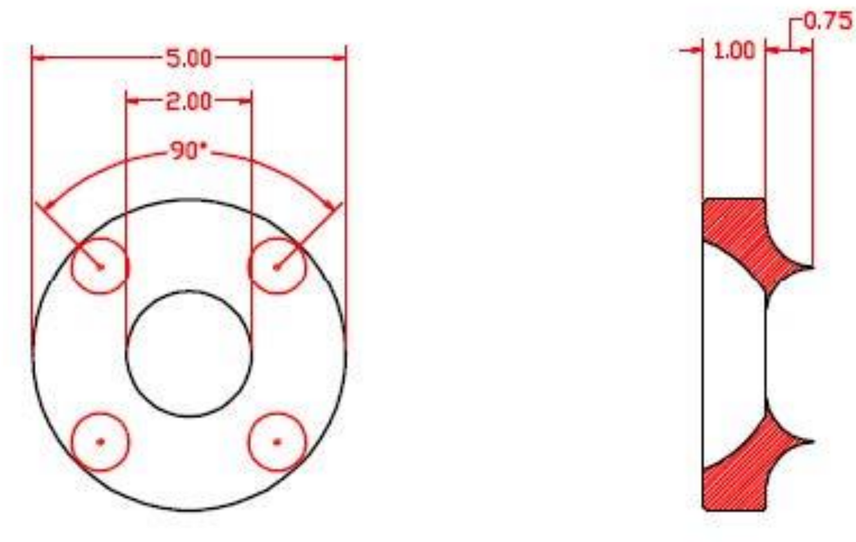


Figure 3.1. Dimensions of the MIR appliance used in the study

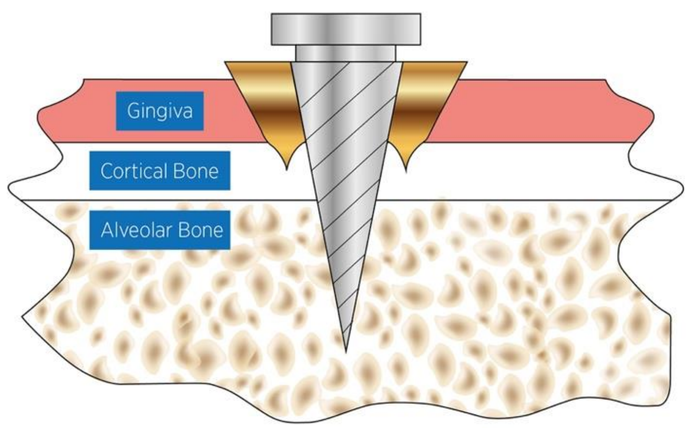


Figure 3.2. Schematic view of the application of the MIR appliance

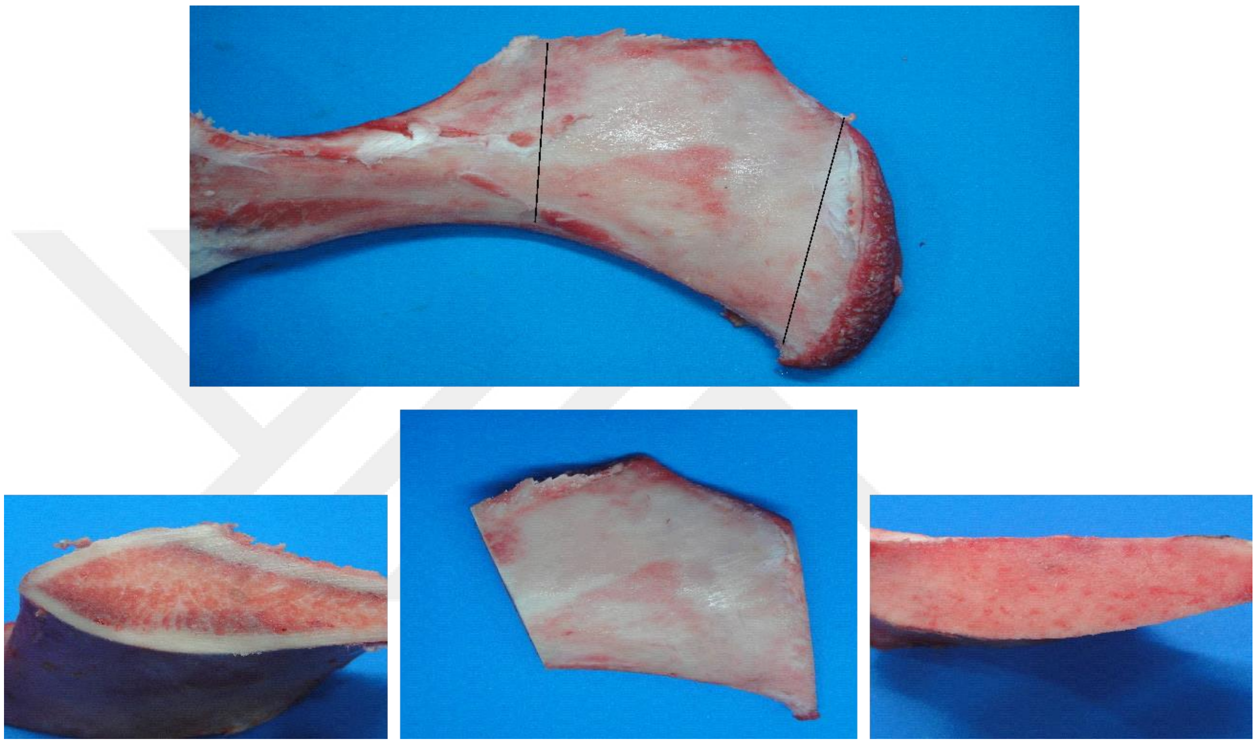


Photo 3.3. Bone sample used in the study

3.1.4. Screwdriver

Trimed Screwdriver: A Trimed screwdriver was used to apply the screws in the study. (Photo 3.4.).

Torque Screwdriver: A Torque screwdriver (N_2DPSK, Nakamura MFG Co Ltd, Tokyo, Japan), the precision of which is guaranteed by the manufacturer, was used to measure the application and extraction torque values (Photo 3.5.). This hand tool was able to measure torque values between 0 and 20 Ncm. In order for the torque screwdriver to be used with the TM mini screw, an additional adapter specially produced for the screwdriver was applied.

3.1.5. MIR Pusher

In the study, a specially designed MIR Pusher hand tool was used to apply pressure so that the protrusions of the MIR were set in in the bone (Photo 3.6.). The outer diameter of the cylindrical part of the MIR Pusher, whose tip is a cylindrical tube, was the same as the outer diameter of the MIR. Thanks to this hand tool, pressure could be applied to the MIR without contact with the mini screw.

3.1.6. Instruments Used in the Inspection of Mini Screw Slots

After removing the mini screws from the bone segment, the samples obtained were divided into two. The incision line was passed through the hole left by the mini screw on the bone. CBT measurements on the screw slots were made with a precision-tipped digital caliper (Guanglu Europa, China) under an illuminated magnifier (Purpose, China) (Photo 3.7.).

3.1.7. Force Testing Device

The Instron device in our faculty was used for the force test (Photo 3.8). Force was applied from a single point with the Instron 3345 universal test device that enabled compression, tensile, hardness and impact strength tests to be made. The device had no bending feature.

Photo 3.4. Trimed Screwdriver

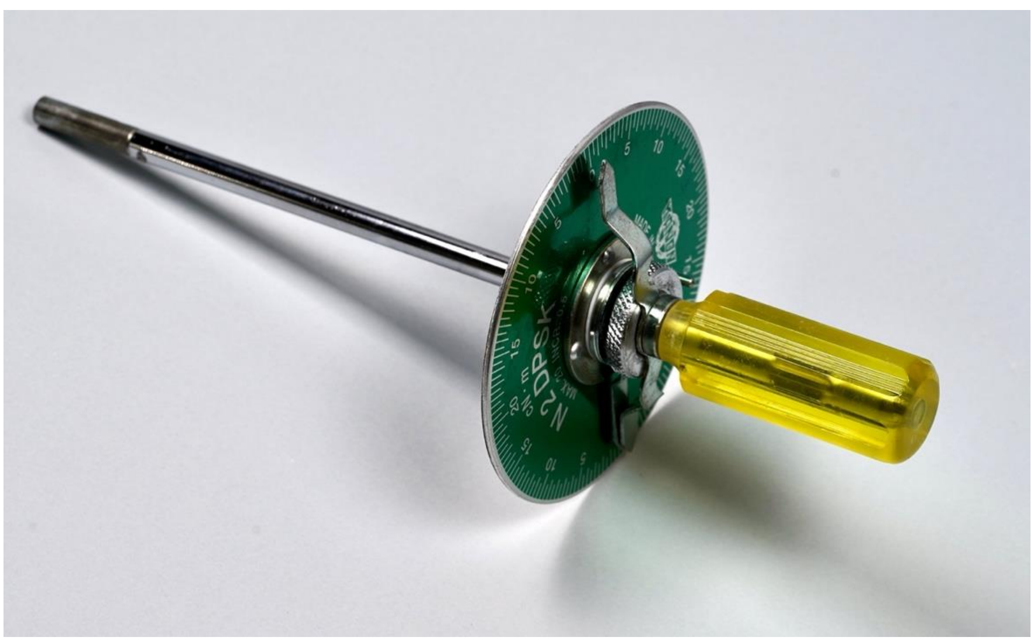


Photo 3.5. Torque Screwdriver

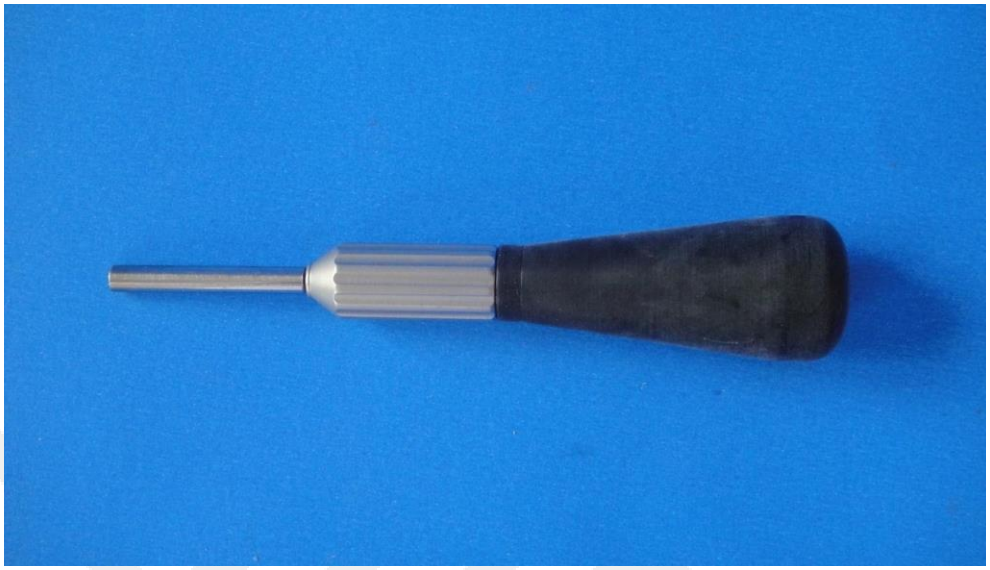


Photo 3.6. MIR Pusher Hand Tool

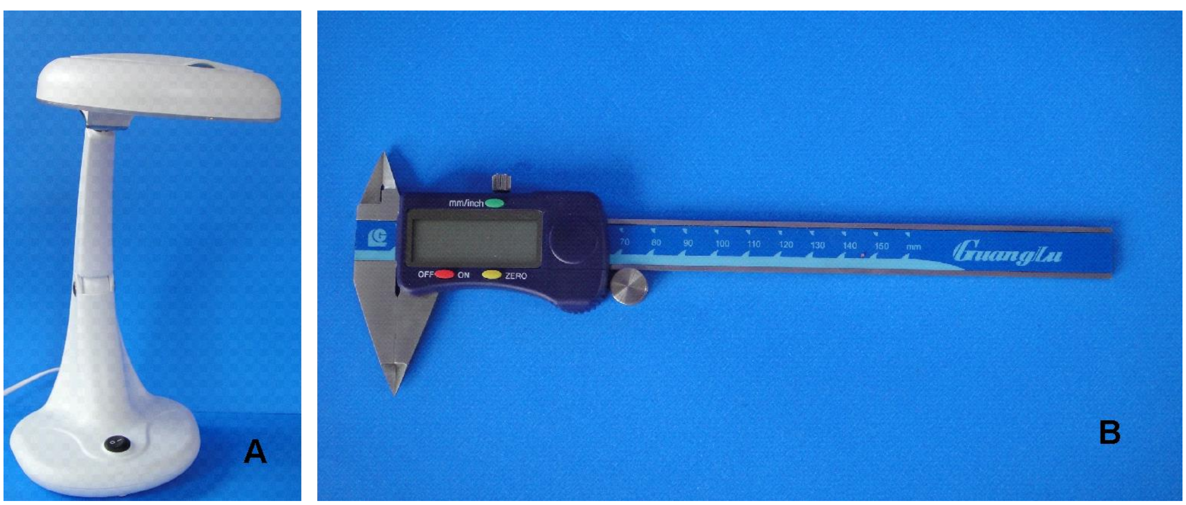


Photo 3.7. Instruments used to measure CBT

A. Illuminated magnifier **B.** Precision-tipped digital caliper

Photo 3.8. Instron test device

3.2. Method Related to Force Test

3.2.1. Preparation of Bone Segments

Twenty bone slices with a width of at least 5 mm were prepared for the placing of 6 mini screws in each slice (Photo 3.9.). Mini screws of 3 different widths with the same lengths were used on each bone. In order to ensure equal distribution of CBT in the test and control groups, care was taken to ensure that one of the mini screws placed side by side was from the test group and that the other was from the control group (Photo 3.10.). Each applied mini screw was numbered from 1 to 120 (Table 3.1 and Table 3.2).

Table 3.1 Numbers of Mini Screws

	6 mm	**8 mm**	**6 mm MIR**	**8 mm MIR**	**Total**
1.4 mm	10	10	10	10	40
1.6 mm	10	10	10	10	40
1.8 mm	10	10	10	10	40
Total	30	30	30	30	120

Table 3.2 Classification of Test and Control subgroups

Screw Diameter	**Screw Length**	**Subgroups**
1.4 mm	6 mm	A
	8 mm	B
1.6 mm	6 mm	C
	8 mm	D
1.8 mm	6 mm	E
	8 mm	F

3.2.2. Application of Mini Screws

TM mini screws were applied without the need to drill a guide hole due to their "self-drilling" feature. In the previous study, it was determined that the MAT value that resulted when the cylindrical mini screws pierced the bone for the first time was always lower than the MAT value that appeared in the last turns. Therefore, the application was carried out with the trimed screwdriver instead of the torque screwdriver until the last turns. The mini screw was tightened 2 mm less on the last application point to perform the torque measurement test. A special apparatus was used to determine this 2 mm distance (Photo 3.11.). 1 mm of this distance was tightened using a torque screwdriver and the maximum application torque was recorded (Photo 3.12a., 3.12b.). The remaining 1 mm distance was the collar of the mini screw and was the area where the gingiva was clinically located. The distance of 1 mm for the mini screws in the control group was determined by a specially made apparatus (Photo 3.12a., 3.12b.). Before the final tightening of the mini screws in the MIR group, MIR Push hand tool pressure was applied to the MIR apparatus and the spiny protrusions were completely inset in the bone (Photo 3.13.). The data obtained were recorded separately for each mini screw in the mini screw number and maximum application torque values table (Excel 2003, Microsoft).

Photo 3.9. Prepared bone slices

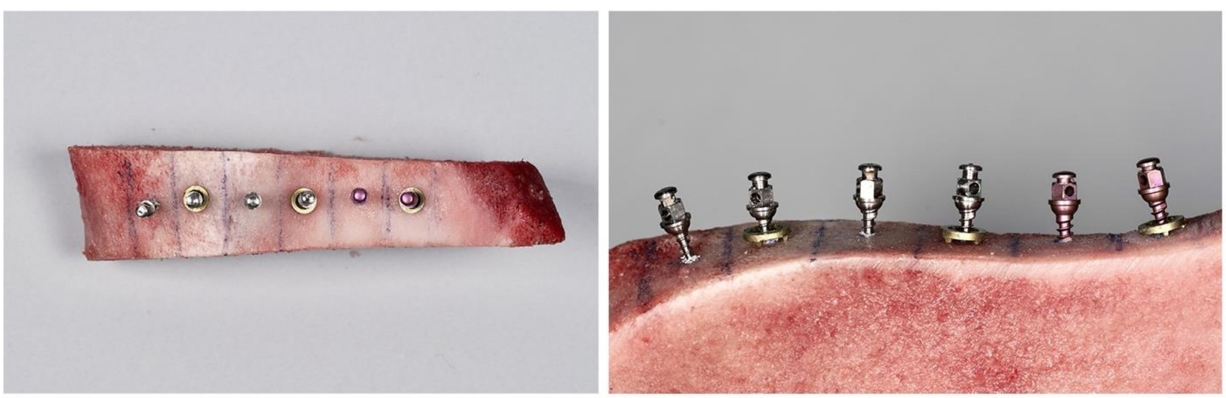


Photo 3.10. Application of mini screws to bone slices

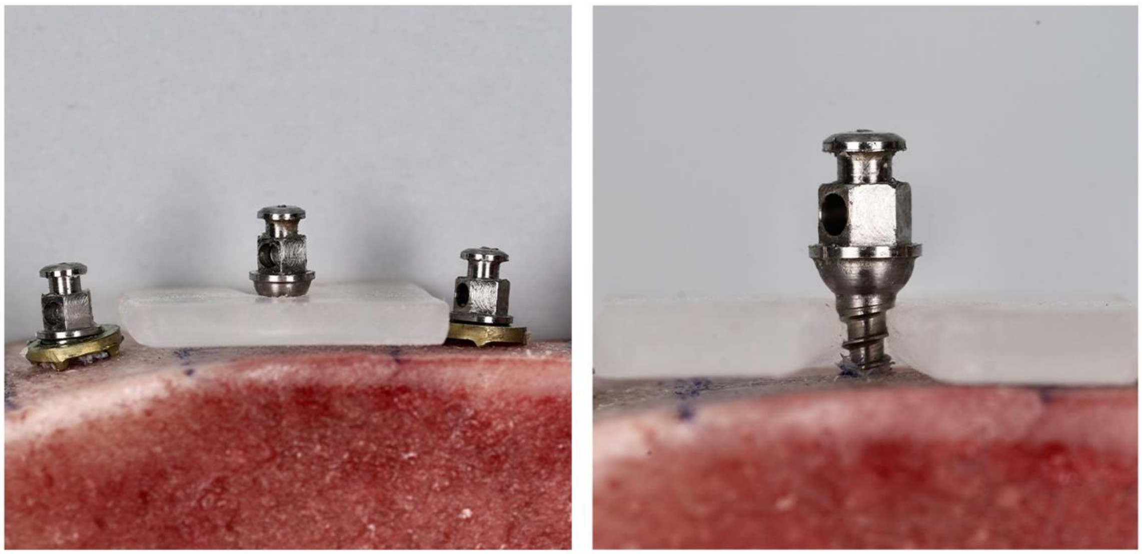
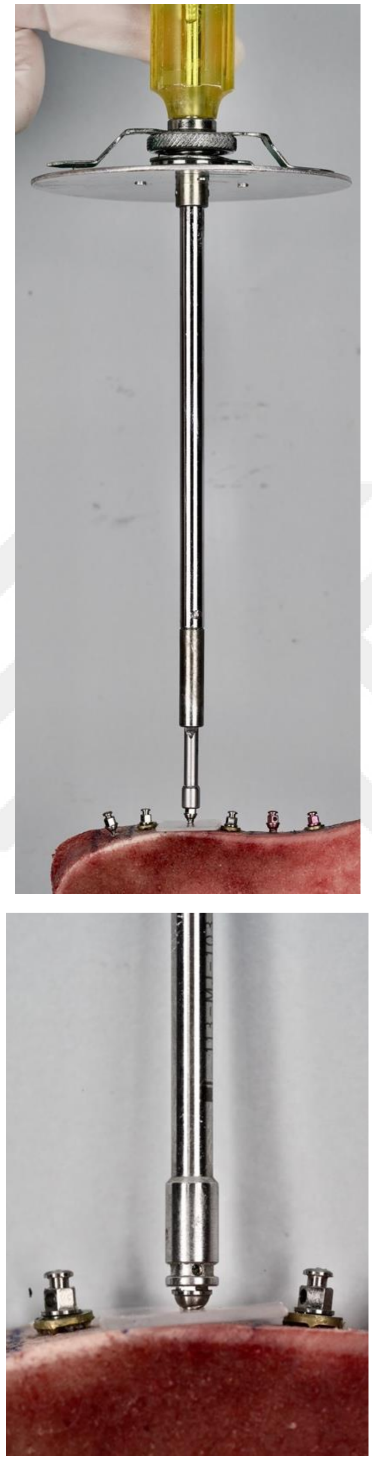


Photo 3.11. Determination of the distance for torque measurement



3.12a, 3.12b. Measurement of the applied torques

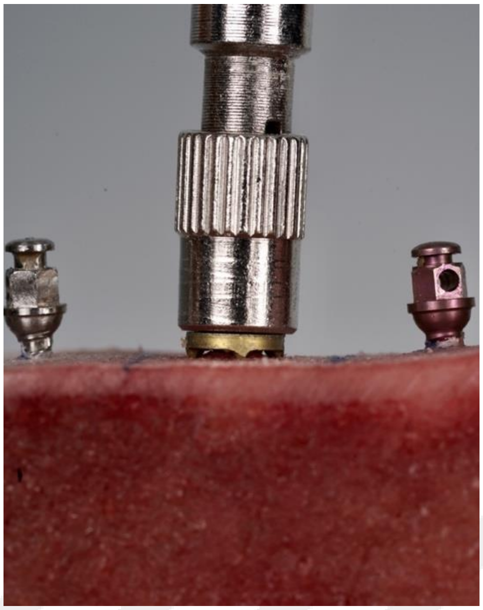


Photo 3.13. Using the MIR Pusher hand tool

Photo 3.14. Applied version of mini screws in the test and control groups

3.2.3. Preparation of Bone Samples to be Transferred to the Adapter

Bones with mini screws were cut under water cooling, leaving 4 mm of bone around each mini screw (96,97,99,150) with attention paid to ensure that the tip of the mini screw did not come out of the cancellous bone (Photo 3.15.). The prepared bone samples were placed in storage bags and numbered to ensure consistent and correct identification until the completion of the study.

3.2.4. Blocking the Bones

A special mechanism was used to block the prepared bone segments (Photo 3.16.). The samples were embedded in cold acrylic (Imicryl, London, England) with the upper surfaces completely excluded. This was done under water cooling to avoid overheating due to polymerization (97) (Photo 3.17.). As a result of this process, samples to be transferred to the test device were obtained (Photo 3.18.).

3.2.5. Application of the Force Test

The strength test was performed on the Instron device (Photo 3.19.). The device had two parts, one fixed and the other movable. The sample to be tested was placed on the fixed part with the help of an adapter. With the help of force transmitters connected to the upper part, which were movable and whose distance could be adjusted, a force was applied until each screw head was displaced by 0.6 mm and their maximum resistances were recorded in Ncm. The distance of 0.6 mm was determined by the previous study and it was the distance from which the screw head had toppled without dragging the mini screw under force.

3.2.6. Mobility Test

After the application of force, each mini screw was evaluated for mobility. Two scores were used - mobility (+) and no mobility (-).

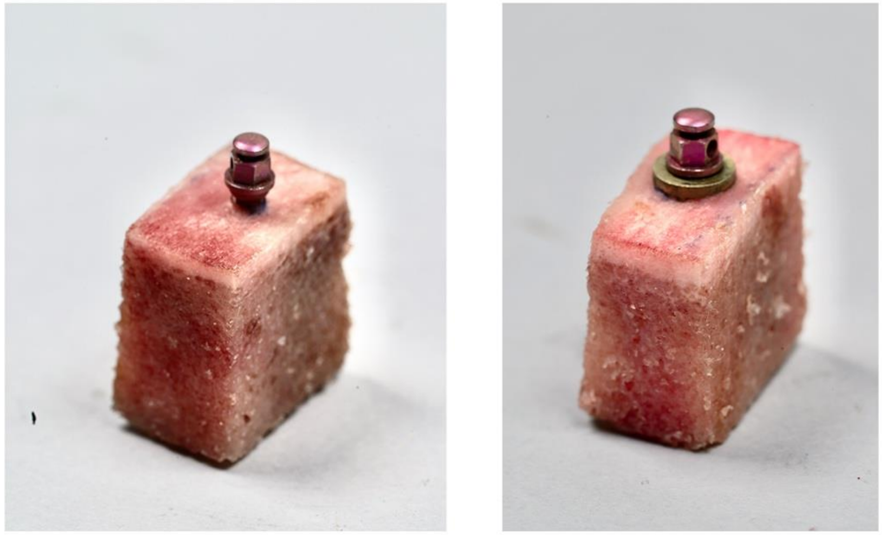


Photo 3.15. Prepared bone segment samples

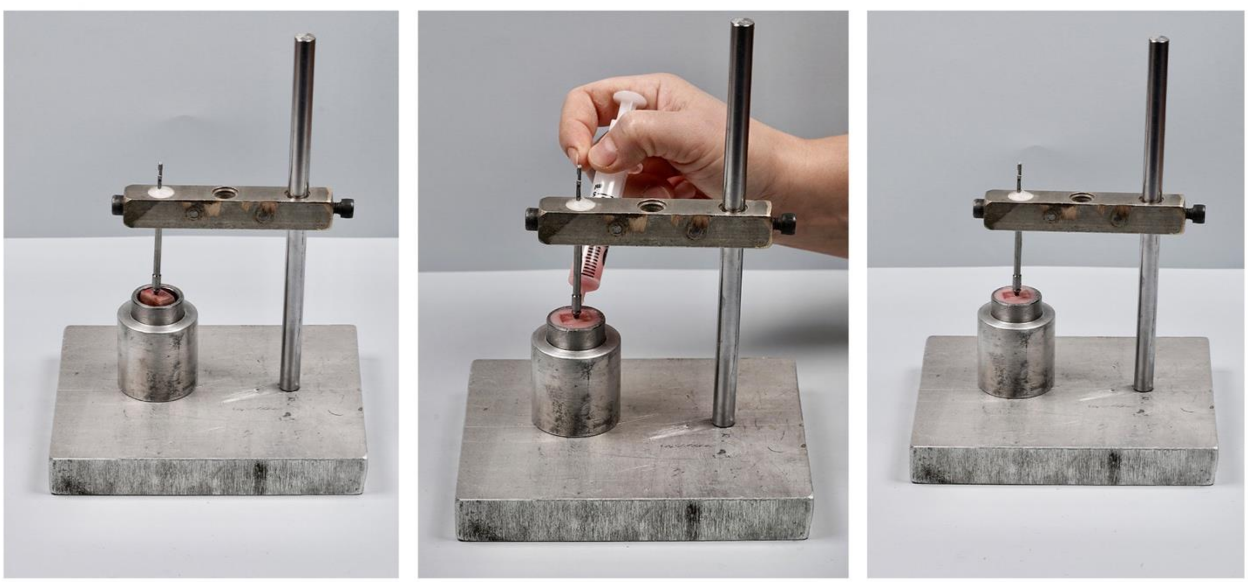


Photo 3.16. Blocking of bone segments

Photo 3.17. Water cooling procedure

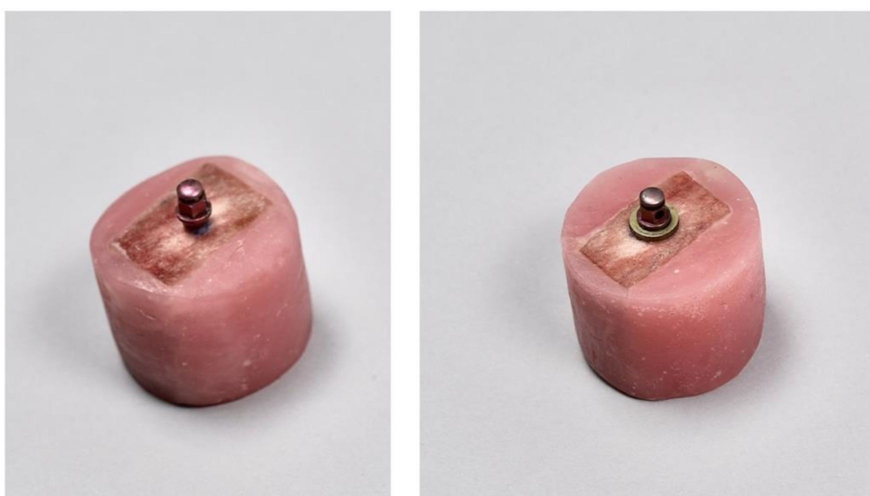


Photo 3.18. Samples prepared to be transferred to the test device

Photo 3.19. Force resistance test

3.2.7. Extraction of mini screws

Each mini screw was removed using a torque screwdriver. MET values were also added to the table where application torques, and mobility results were recorded previously.

3.2.8. Measurement of Cortical Bone Thicknesses (CBT)

After measuring the maximum application and extraction torque values and force resistances of each mini screw, the cortical bone thickness were also measured to determine the subgroups. In order to measure CBT, bone segments were cut so that the incision line passed through the mini screw holes (Photo 3.21.). CBT was measured using a digital caliper. The measurements were repeated 3 times by the same investigator at different times (Photo 3.22.). These values were recorded in the previously created data table. The average of three repeated measurements was used for statistical analysis.

3.3. Statistical Analysis

The SPSS 26.0 (IBM Corporation, Armonk, New York, United States) program was used in the analysis of variables. The suitability of univariate data to normal distribution was evaluated with the Shapiro-Wilk Francia test, while variance homogeneity was evaluated with the Levene test. The Independent-Samples T test was used together with the Bootstrap results, while the Mann-Whitney U test was used with the Monte Carlo results in comparing two independent groups with each other according to quantitative data. The Univariate (ANOVA) Analysis of Variance (Robust Statistic: Brown-Forsythe) test, which is one of the parametric methods, and the Fisher's Least Significant Difference (LSD) test were used for Post Hoc analyzes, while the Kruskal-Wallis H test was used with the Monte Carlo simulation technique results, and the Dunn's Test was used for the Post Hoc analyzes. In comparing categorical variables with each other, the Fisher's exact test was used with Exact results. Quantitative variables were expressed as mean ± SD (standard deviation) and median (Minimum / Maximum) in the tables, while categorical variables were shown as n (%). Variables were examined at a 95% confidence level and were considered significant when the p-value was less than 0.05.

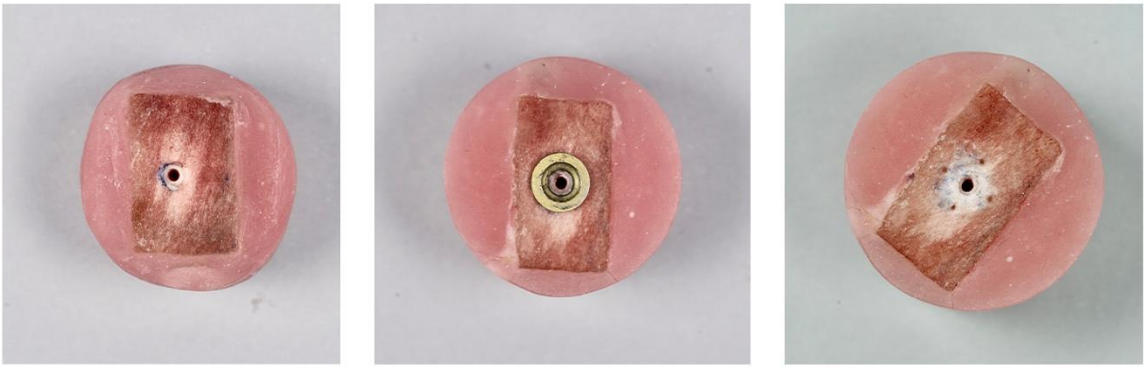


Photo 3.20. Images of bone specimens after mini screws were removed

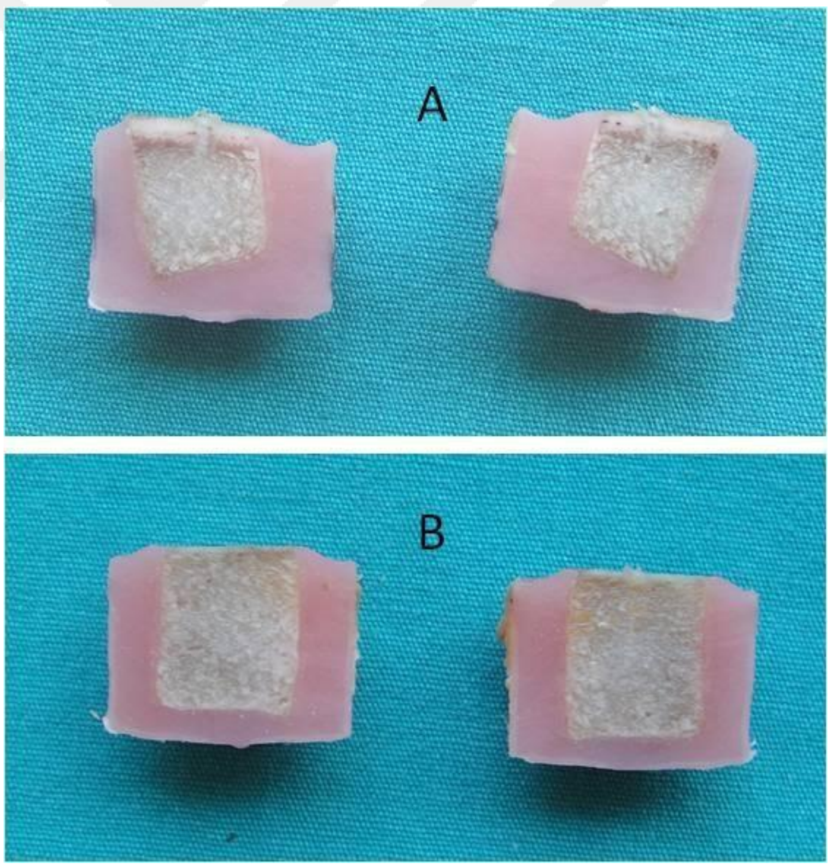


Photo 3.21. Cut bone samples **A.** Sample from the thick group **B.** Sample from the thin group

Photo 3.22. Measurement of bone thicknesses

4. RESULTS

Tests were performed using TM mini screws containing 60 MIRs in the study group and 60 non-MIRs in the control group, and the data in relation to MAT, MET, mobility, FR, and cortical bone thickness were evaluated.

4.1. Results Related to Cortical Bone Thickness

The present study showed no statistically significant difference between the test group and the control group in terms of cortical bone thickness ($p > 0.05$) (Table 4.1).

Table 4.1 Cortical bone thicknesses of MIR control groups

SD.	SL.	Cortical bone thickness (mm)		P Value [t]
		Control (MIR -)	Experimental (MIR +)	
		Mean±SD.	Mean±SD.	
1.4 mm				
6 mm	**A**	1.18±0.16	1.18±0.16	0.968
8 mm	B	1.18±0.13	1.21±0.10	0.566
1.6 mm				
6 mm	C	1.15±0.19	1.23±0.14	0.347
8 mm	**D**	1.22±0.11	1.21±0.10	0.901
1.8 mm				
6 mm	E	1.20±0.16	1.21±0.15	0.882
8 mm	F	1.22±0.12	1.23±0.09	0.761
P Value [o]		0.926	0.973	

[o] Univariate (ANOVA) Analysis of Variance(Robuts Statistic:Brown-Forsythe), [t] Independent Samples T Test (Bootstrap), SD. Standard Deviation, SD.:Screw Diameter, SL.: Screw Length

4.2. Results Related to the Application Torque

As the screw diameter increased in both test and control groups, the MAT values increased ($p=0.001$, $p=0.003$). When the MAT values of the MIR and control groups were compared, the MAT values of all screw lengths and diameters of the MIR group were found to be significantly higher (p <0.05). In the control group, the MAT value of the screws with a diameter of 1.8 mm and a length of 6 mm and 8 mm was found to be statistically significantly higher than the MAT value of a 1.4 mm diameter and 6 mm long screw (p=0.024, p <0.001). The MAT value of the 1.8 mm diameter and 6 mm and 8 mm long screws was found to be statistically significantly higher than the MAT value of the 1.4 mm diameter and 8 mm long screw (p=0.030, p <0.001). The MAT value of the 1.8 mm diameter and 6 mm and 8 mm long screws was found to be statistically significantly higher than the MAT value of the 1.6 mm diameter and 6 mm long screw (p=0.037, p <0.001).

The MAT value of the 1.8 mm diameter and 8 mm long screws was found to be statistically significantly higher than the MAT value of the 8 mm long screws with a diameter of 1.6 mm (p=0.023).

When the MAT values of the test group were compared, the MAT values of 1.8 mm diameter and 6 mm and 8 mm long and 1.6 mm diameter and 8 mm long screws were found to be statistically significantly higher than the MAT value of the 1.4 mm diameter 6 mm long screw (p=0.018, p=0.016, p <0.001). The MAT value of the 1.8 mm diameter, 6 mm and 8 mm long screws was found to be statistically significantly higher than the MAT value of the 1.4 mm diameter and 8 mm long screw (p=0.047, p=0.001).

In the comparison of the subgroups, the application torque of the 1.8 mm diameter and 8 mm screws was found to be significantly higher in both the control and MIR groups compared to the other groups.

Table 4.2 Comparison of MIR and control group MAT values

SD.	SL.		Absolute Application Torque (Ncm)		P Value [t]
			Control (MIR -)	Experimental (MIR +)	
			Mean±SD.	Mean±SD.	
1.4 mm					
	6 mm	**A**	6.76±2.17	10.80±2.34	**0.002**
	8 mm	B	6.89±2.87	11.37±3.55	**0.007**
1.6 mm					
	6 mm	C	7.02±1.62	13.12±4.01	**0.006**
	8 mm	**D**	9.22±3.53	14.34±2.85	**0.005**
1.8 mm					
	6 mm	E	10.02±3.96	14.39±3.70	**0.023**
	8 mm	F	12.51±3.91	16.55±2.76	**0.019**
P Value [O]			**0.001**	**0.003**	
	A→B		0.926	0.704	
	A→C		0.854	0.124	
	A→D		0.085	**0.018**	
	A→E		**0.024**	**0.016**	
	A→F		**<0.001**	**<0.001**	
	B→C		0.926	0.254	
	B→D		0.102	0.051	
	B→E		**0.03**	**0.047**	
	B→F		**<0.001**	**0.001**	
	C→D		0.122	0.416	
	C→E		**0.037**	0.397	
	C→F		**<0.001**	**0.025**	
	D→E		0.571	0.973	
	D→F		**0.023**	0.132	
	E→F		0.081	0.141	

[O] Univariate (ANOVA) Analysis of Variance(Robuts Statistic:Brown-Forsythe); Post Hoc Test: Fisher's Least Significant Difference (LSD), [t] Independent Samples T Test (Bootstrap), SD. Standard deviation, SD.:Screw Diameter, SL.: Screw Length

4.3. Results Related to Extraction Torque

When the MET values between the two groups were examined, no significant difference was observed between the MIR and control groups ($p > 0.05$), while the MET value was found to be significantly higher as the screw diameter and screw length increased in both MIR and control groups (p=0.023, p=0.026). When the subgroups were evaluated among themselves, the MET values of the 1.4 mm diameter and 6 mm long screw were found to be significantly lower than the MET values of the 1.6 mm diameter and 8 mm and 1.8 mm diameter and 6 mm and 8 mm long screws, respectively (p=0.035, p=0.039, p=0.012). Again, the MET values of the 1.4 mm diameter and 8 mm long screws were found to be statistically significantly lower than the MET values of the 1.6 mm diameter and 8 mm long screws (p=0.034) and the 6 mm and 8 mm long screws with 1.8 mm diameter, respectively (p=0.038, p=0.012). The comparison of MET values is included in Table 4.3.

Table 4.3 Comparison of MET values of the MIR and control groups

SD.	SL.		Absolute Extraction Torque (Ncm)		P Value [u]
			Control (MIR -)	**Experimental (MIR +)**	
			Median (Min. / Max.)	**Median (Min. / Max.)**	
1.4 mm					
	6 mm	**A**	2.05 (0.30 / 5.70)	2.60 (0.90 / 8.20)	0.438
	8 mm	B	3.00 (0.70 / 9.10)	3.30 (0.80 / 7.80)	0.983
1.6 mm					
	6 mm	C	3.80 (1.70 / 5.70)	4.20 (1.10 / 10.90)	0.614
	8 mm	**D**	4.65 (1.30 / 12.30)	6.25 (1.70 / 13.60)	0.346
1.8 mm					
	6 mm	E	5.65 (2.10 / 9.80)	5.45 (2.80 / 10.90)	0.840
	8 mm	F	5.60 (1.70 / 15.30)	6.50 (3.40 / 15.40)	0.322
P Value [k]			**0.026**	**0.023**	
	A→B		0.461	0.946	
	A→C		0.114	0.346	
	A→D		**0.018**	**0.035**	
	A→E		**0.004**	**0.039**	
	A→F		**0.011**	**0.012**	
	B→C		0.398	0.325	
	B→D		0.104	**0.034**	
	B→E		**0.033**	**0.038**	
	B→F		0.069	**0.012**	
	C→D		0.435	0.268	
	C→E		0.198	0.285	
	C→F		0.33	0.133	
	D→E		0.613	0.968	
	D→F		0.848	0.686	
	E→F		0.754	0.657	

[u] Mann Whitney U test(Monte Carlo), [k] Kruskal Wallis Test(Monte Carlo);Post Hoc test: Dun’s Test, Min.:Minimum, Max. Maximum, SD.:Screw Diameter, SL.: Screw Length

4.4. Results Related to Force Resistance

Findings related to force resistance are given in Table 4.4. The force resistance of 1.4 mm diameter and 6 mm long screws was significantly higher in the MIR group compared to that of the control group (p=0.002). Again, in the MIR group, the force resistance of a 1.6 mm diameter and 8 mm long screw was found to be significantly higher compared to that in the control group (p=0.026). There was no significant difference in other parameters (Figure 4.1).

There was no statistically significant difference in force resistance between the subgroups in the classification of screws in the MIR and control groups according to their lengths and diameters (p=0.867, p=0.078).

Table 4.4 Comparison of MIR and control group force resistance values

SD.	SL.		Force Resistance (N)		P Value [u]
			Control (MIR -)	**Experimental (MIR +)**	
			Median (Min. / Max.)	**Median (Min. / Max.)**	
1.4 mm					
	6 mm	**A**	23.27 (8.78 / 34.25)	41.83 (21.73 / 82.26)	**0.002**
	8 mm	B	21.03 (4.99 / 139.80)	46.15 (14.02 / 188.30)	0.213
1.6 mm					
	6 mm	C	24.64 (13.06 / 41.38)	39.67 (20.63 / 83.42)	**0.026**
	8 mm	**D**	44.18 (18.69 / 90.70)	43.34 (9.58 / 96.10)	0.741
1.8 mm					
	6 mm	E	24.37 (18.57 / 45.25)	45.47 (10.91 / 108.60)	0.06
	8 mm	F	46.44 (12.16 / 145.10)	54.44 (24.92 / 181.80)	0.354
P Value [k]			**0.078**	**0.867**	

[u] Mann Whitney U test(Monte Carlo), [k] Kruskal Wallis Test(Monte Carlo), Min.:Minimum, Max. Maximum, SD.:Screw Diameter, SL.: Screw Length

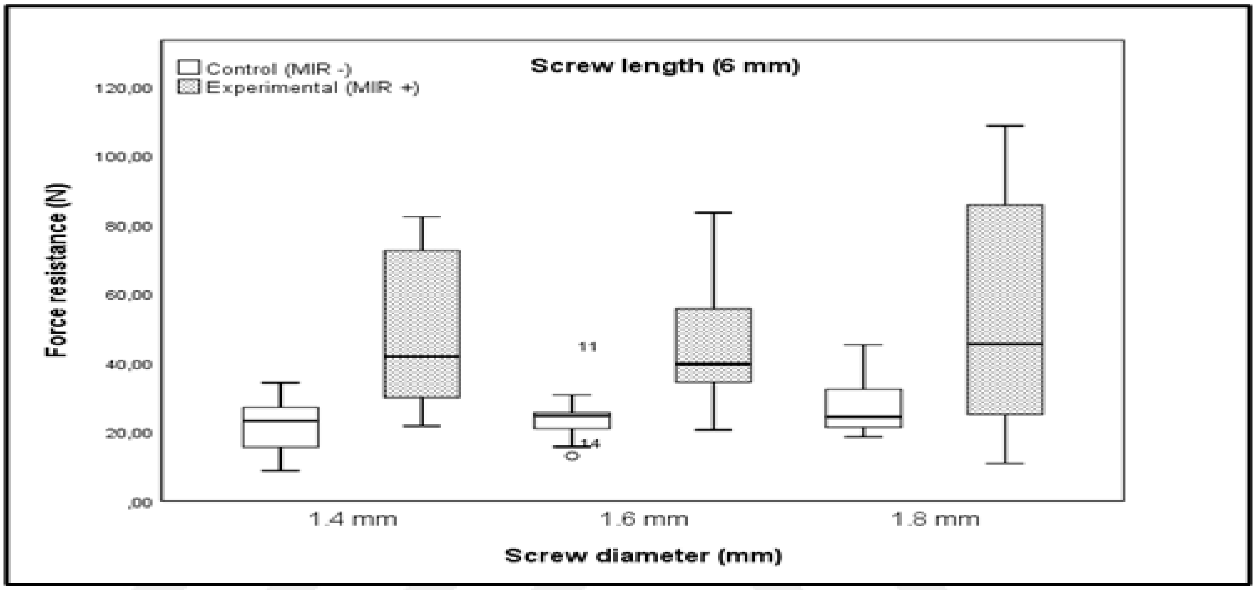


Figure 4.1 Force resistance of 6 mm long mini screws in the MIR group

4.5. Mobility Test

The mobility test data are included in Table 4.4. There was no statistically significant difference between MIR and control group mobility (p> 0.05). When the subgroups were evaluated among themselves, there was no statistically significant difference between the MIR group and the control group (p> 0.05).

Table 4.5 Mobility Test data

SD	SL	Mobility	Control (MIR -) n (%)	Experimental (MIR +) n (%)	p
1.4 mm	**6 mm**	Absent	6 (60.0)	8 (80.0)	0.628
		Present	4 (40.0)	2 (20.0)	
	8 mm	Absent	7 (70.0)	7 (77.8)	0.999
		Present	3 (30.0)	2 (22.2)	
1.6 mm	**6 mm**	Absent	10 (100.0)	9 (100.0)	-
		Present	0 (0.0)	0 (0.0)	
	8 mm	Absent	9 (90.0)	10 (100.0)	-
		Present	1 (10.0)	0 (0.0)	
1.8 mm	**6 mm**	Absent	10 (100.0)	10 (100.0)	-
		Present	0 (0.0)	0 (0.0)	
	8 mm	Absent	10 (100.0)	10 (100.0)	-
		Present	0 (0.0)	0 (0.0)	

Fisher Exact test(Exact)

5. DISCUSSION

5.1. Discussion on Purpose, Material and Method

Anchorage (stability) is defined as the resistance to unwanted tooth movement (156). During orthodontic treatment, different forces and moments occur in the same magnitude and opposite direction with the force applied to the teeth in accordance with Newton’s action-reaction law. Therefore, anchorage control is quite important in the success of orthodontic treatment. The determination of anchorage units or moving units in orthodontic treatment depends on the orthodontist’s knowledge of the response of tissues to mechanical forces and their application (157, 158). The mechanical stability obtained immediately after insertion of the mini screw is called "primary stability" and plays an important role in the response of the mini screw to orthodontic force loading. Important factors affecting primary stability can be listed as bone quality, quantity, the physical properties of the mini screw and surgical technique (154).

The quest to increase the success of the mini screw has led to the design of additional stability enhancing devices when factors related to bone quality cannot be eliminated. Tozlu (10) introduced the MIR apparatus with the aim of increasing the support of the mini screws on the cortical bone and thus the initial stability of the mini screw. The MIR apparatus is placed on the neck of the mini screw and adheres to the cortical bone with spike protrusions and increases the surface contact area of the mini screw with the cortical bone and thus its adhesion. It has been shown that the MIR apparatus increases the initial stability, especially in cases with reduced cortical bone thickness.

This study aimed to investigate the effect of the MIR appliance on strength resistance and stabilization when used with mini screws of different lengths and diameters in vitro. Mini screws of different lengths and diameters were placed in bovine hip bones together with the MIR appliance and it was aimed to determine the optimum usage method of the MIR apparatus by examining the application and removal torque values as well as force resistance values.

Application torque (45, 142) and extraction torque measurement (52, 143) and Osstell's RFA used in primary stability measurement stand out as more reliable methods (144).

Application torque analysis is a frequently used method for measuring mechanical adhesion obtained by screwing (30, 32, 33, 45,47, 63,140, 150, 160). Extraction torque analysis is used to measure osseointegration and the stability of mini screws and mini-implants (52, 55, 60, 129, 145, 151, 152). Both values were measured in this study. It has been suggested that the force resistance of mini screws can be increased when they are used with mini screws of different lengths and diameters thanks to the MIR apparatus. Two specific questions should be addressed: when trying to achieve increased force resistance, is the application torque excessively increased and stability adversely affected due to the protrusions of the MIR apparatus? How will the removal torques after the force resistance test be affected? MAT and MET values were measured in order to obtain answers to these questions. In addition, after the strength test, the mini screws were evaluated for mobility.

This in vitro study does not reveal the biological changes that MIR and mini screw may cause in bone tissue as a result of force application. However, unlike dental implants, which require waiting periods for bone healing and osseointegration, it is believed that mini screws gain their stability from the mechanical locking they make with cortical bone (43, 126). Therefore, it is thought that in vitro studies with mini screws can almost exactly reflect the force resistance that would occur with immediate loading on living tissues.

To date, animal bones such as bovine thigh bone (161), porcine rib (50), canine femur (162), sheep skull bone (163), and pig hip bone (32, 33, 45, 141) have been used in screw studies. Human cadaver bones (47, 93, 92) and artificial bones (160, 47, 52 152) have also been used. In the present study, bovine hip bone was used. In this study, the section facing the iliosacral joint with a thickness of 2.0–2.5 mm at most was preferred. These values are consistent with the human upper and lower jaw CBT (9, 65, 153, 154).

The thickness of the CBT used in the study varied between 1.18-1.23 mm. This value is compatible with the human lower and upper jaw CBT value.

In addition to primary stability and force resistance, it should be kept in mind that there are other factors that may affect mini screw stability and success, such as soft tissue inflammation, the severity and shape of the orthodontic force applied, the patient's age and oral hygiene status. In addition, although the bone models used did not accurately reflect living human bone tissue, this study was not intended to represent viable bone tissue, because there is no need for a waiting period for bone healing and osseointegration in mini screws like that required in dental implants.

Mini screws gain their stability from the mechanical locking they make with cortical bone (43). In this study, bone samples obtained from a certain part of the bovine hip bone and having a certain cortical thickness allowed us to standardize the test conditions.

Conical mini screws were preferred in the study. Studies have shown that conical mini screws show better primary stability compared to those which are cylindrical (32, 58). A tighter bone-screw relationship is advantageous and achieves a higher MAT with conical screws with a structure that expands towards the neck. However, excessive torque values encountered in cases where cortical bone is thick and dense affect the success of the mini screw negatively (7). An animal study conducted by Cha et al. (60) (2008) revealed that there is no difference between the secondary stability of conical and cylindrical mini screws. According to the results of the study examining the primary and secondary stability of mini screws, conical mini screws under loading showed a higher MET value after 3 weeks (primary stability), while there was no difference in MET values between conical and cylindrical screws at the 12th week (secondary stability). Clinically, considering the time required for tooth or tooth group movement, it is evident that the secondary stability of a mini screw used for anchoring is more important and the cylindrical structure does not present a disadvantage. Considering the tight screw positioning between the roots the conical screws are less likely to cause root damage. Therefore, in the present study, conical screws are preffered instead of cylindrical screws.

5.2. Discussion of Results

When the application torques were evaluated in the study, MAT values were found to be significantly higher in the MIR group compared to those in the control group. In the comparison of subgroups, the maximum application torque of 1.8 mm diameter and 8 mm screws was significantly higher in both the control and MIR groups compared to those in the other groups. Based on these findings, it is possible to say that the application torque increases with the use of the MIR appliance. In addition, the use of the MIR apparatus in thick and long screws causes an increase in application torque.

The application torque value is affected by the guide hole diameter drilled before the application, the inner diameter of the mini screw and the thread properties, the application technique (bicortical or monocortical), intermittent or continuous screwing, and application in humid or dry conditions (161).

Conical screws have a greater application torque than cylindrical ones. The conical structure causes a sudden increase in torque in the last two to four rounds before reaching the maximum value (52). This increases the risk of screw breakage. Particular attention should be paid to the use of conical mini screws, especially if the distance between the roots is small and small diameter mini screws are to be used. In the present study, the MAT value was found to be significantly higher in the MIR group compared to that in the control group. This result is within the limits recommended by previous researchers for successful mini screw applications (30, 32, 164).

MAT values recorded in the study are higher than the values measured using cylindrical mini screws of similar diameter in some studies (32,33,45, 141). The reason for this may be that in these studies, the researchers drilled guide holes and the opening of the guide hole or even the increase in the diameter of the opened guide hole resulted in a decrease in the application torque values (33, 45). Another possible reason is that the MIR Pusher hand tool ensures that the spine protrusions of the MIR apparatus are fully settled on the bone and the maximum insertion torque values are obtained with the help of 1 mm apparatus in the maximum insertion torque measurements of the mini screw groups with MIR, before the final tightening process. It is measured during the last 1 mm compression. The reason why the MAT values of the MIR groups are higher than the MAT values of the control groups in the present study may be that the spinous protrusions of the MIR apparatus fit to the bone during this last 1 mm compression process and the neck of the mini screw leans against the MIR apparatus. However, the results we obtained are consistent with the results obtained by Brinley et al. (47), who applied the mini screws to cadaver bone without drilling a guide hole. In the study, in the subgroup evaluation of both MIR and control groups, the MAT values of 1.8 mm diameter screws were found to be significantly higher in both the control and test groups. In other words, the MAT values of the 1.4 mm diameter screws were found to be significantly lower. Although there are many factors affecting the primary stability, the length, diameter and application angles of the mini screws to be applied are important while cortical bone density stands out among patient-related factors. In the present study, the use of the MIR apparatus also makes sense in relation to thin screws. The use of 1.8 mm diameter screws does not appear to be significant in terms of primary stability, since they cause an increase in MAT and MET values and also do not differ in strength resistance.

When the MET values between the test and control groups were examined, no significant difference was observed between the MIR and control groups, while the MET value was found to be significantly higher as the screw diameter and length increased in both MIR and control groups. When the subgroups were evaluated among themselves, the MET values of the 1.4 mm diameter and 6 mm long screws were significantly lower than the MET values of the 1.6 mm diameter and 8 mm, and 1.8 mm diameter and 6 mm and 8 mm long screws, respectively. Again, the MET values of the 1.4 mm diameter and 8 mm long screws were found to be statistically significantly lower than the MET values of the 8 mm long screws with 1.6 mm diameter and 6 mm and 8 mm long screws, respectively.

When the extraction torques in the study were evaluated, although the MIR group showed higher MET values, no statistically significant difference was found with the control group.

The aim of this study was to increase the mini screw force resistance by applying the MIR apparatus to the mini screws. In addition, it was aimed to find out what effect MIR application would have on application and removal torques. It was thought that the possible positive results obtained as a result of the force test should be supported by both MAT and MET measurements, because both measurements were methods used in primary stability tests on their own. In this study, in addition to obtaining increased force resistance and stability (anchorage) according to the force resistance test results, application and extraction torques were recorded at desired levels.

Comparing the values obtained in the studies in which the extraction torque was tested with the values obtained in the current study, higher results are often found in other studies using thicker mini screws compared to those used here (52,145,151, 152). This difference can be explained by the effect of the mini screw diameter, that is, the extraction torque is directly proportional to the square of the implant diameter (73). In the study, the difference between MAT and MET values and the difference between the data in studies measuring both values were consistent (52,60.129). In a study using different artificial cortical bone thicknesses, a higher MET value was recorded than the findings obtained in this study and those in other studies (152). This result may be due to the properties of the cortical artificial bone.

In the study, the MET values in the MIR group were higher than those of the control group. However, the results did not exceed the significance level. The purpose of measuring MET in this study is not because of our claim to achieve significantly increased values of extraction torque. While increased force resistance was achieved with the MIR group, an unwanted decrease or increase in application and extraction torque was not expected because the researchers took measures at the start of the procedure. For example, the unwanted possible increase in application torque was avoided using the MIR Push handpiece. As a result, the MET findings obtained in our study were at an acceptable level.

In the MIR group, the force resistance of 1.4 mm diameter and 6 mm and 1.6 mm diameter and 8 mm long screws was found to be significantly higher than that in the control group. There was no significant difference in other subgroups.

Orthodontic forces in a certain range of intensity trigger bone formation around implants (123, 124, 148), while excessive forces increase bone resorption (110, 125). Bone formation occurring around the implant within a certain force range is on the pressure side of the implant, and increased resorption occurs in the opposite direction of the force, ie in the tension part (122, 123). The strain created by the forces occurs around the first threads that start in the neck of the mini screw and is a possible cause of bone resorption (166). As a result of the present study, it is obvious that mini screws 1.4 and 1.6 mm in diameter and 6 mm and 8 mm in length with MIR are more stable. With MIR mini screws, it can be thought that the excessive stress that will occur on the first threads can be reduced and the stress on the bone on the pressure and tension side of the mini screw will be more balanced.

As a result of the mobility test, mini screws were found to exhibit less mobility in the MIR group compared to those in the control group. However, the values were not significant.

5.2.5. Overview

In this study, in which the effect of the MIR apparatus on strength resistance and stabilization when used with mini screws of different lengths and diameters in an in vitro environment was investigated, application torques increased in mini screws using the MIR apparatus and this increase did not exceed the desired levels. A nonsignificant increase in extraction torques was also noted. These results reveal that the MIR apparatus is effective in increasing the force resistance and stability of mini screws in certain dimensions. It is considered that the highest stability increase in the study was shown by the 1.4 mm diameter and 6 mm long screw due to the higher force resistance compared to that in the control group and the MAT values still within the range reported in the literature.

The mini screw surface area in contact with the cortical bone is directly related to mini screw stability. As the diameter of the mini screw increases, the contact area increases, and this directly affects stability. Mini screw stability is directly proportional to the mini screw surface area in contact with cortical bone (10.30.31).

Screw diameter used in mini screw studies generally varies between 1.0 and 2.3 mm. In a meta-analysis by Alharbi et al. (2018) where the success rates in studies were evaluated, it was reported that the failure rate for screws with a diameter smaller than 1.3 mm was 10.7%, for screws with a diameter of 1.4-1.6 mm, it was 13.6%, and for screws with a diameter of 1.7-2 mm, it was 14.4%. However, it was noted that the failure rate increased with the increase in screw diameter and that the number of patients included in the meta-analysis was significantly lower in studies using thin screws (165). In a study by Miyawaki et al., it was reported that the success rates of 1.5 and 2.3 mm diameter mini screws were the same, and they were significantly more successful than 1.0 mm diameter mini screws (2). Similarly, in vitro studies on porcine iliac bone show that there is a statistically significant relationship between mini screw diameter and mini screw stability (32,33). The diameter of the screw is directly proportional to its resistance to breakage. Due to the risk of fracture during application with small diameter mini screws (44-46), mini screws with a diameter smaller than 1.3 mm should not be applied especially in the lower jaw where the cortical bone is thick (34,35). There are studies reporting that mini screws with this diameter have broken (4,5). When evaluated from this aspect, it was seen that the stability of thin-diameter screws can be increased by using the MIR apparatus as per the results of the present study.

Studies have shown that the screw length does not affect mini screw success (2,7). The length of the mini screw to be applied is determined mainly according to the thickness of the mucosa, application angle, proximity of adjacent structures and bone quality (6, 37-39). Short screws applied in the palatal part may be lost due to thick mucosa (6, 40). Since the screw length in the bone may be insufficient in areas of thick mucosa, it is recommended to use longer mini screws in this area (41,42). The mini screw takes its attachment mainly from cortical bone, and in angled applications, the application depth in the bone should be at least 5-6 mm in order to provide contact with the whole cortical bone (6,43,44). If the length of the mini screws is longer than 5 mm, their stability is not affected by their length (2). There are also publications in the literature reporting that mini screw length is effective on its own (4,6,10). In their in vitro study, Wilmes and Drescher concluded that the depth of application in itself significantly increased the stability of the mini screw primer (45). On the other hand, different results were revealed in some studies. In the literature, the shortest screw ever used was used in an animal study and was 3 mm. Except for unusual situations with animals seen in this study, it was observed that the success rates of the 3 mm and 6 mm length mini screws did not make a statistical difference. However, the entire cortical bone had to be traversed by both lengths of mini screws (40). Similarly, in the current study, differences in screw diameters rather than screw lengths stand out in the test group.

CONCLUSION

1- The MIR apparatus significantly increased the force resistance and anchorage value of the mini screws for every diameter and lengths, albeit partially.

2- The force resistance of screws 1.4 mm in diameter and 6 mm in length and 1.6 mm in diameter and 8 mm in length was found to be significantly higher than that in the control group.

3- The highest stability increase is shown by 1.4 mm diameter and 6 mm long screws due to their higher strength compared to that seen in the control group and the MAT values are within the range reported in the literature. The necessity of the MIR appliance in the application of 1.8 mm diameter screws remains controversial.

4- The MIR apparatus did not cause a significant change in the extraction torques of mini screws.

5- As a result of MIR apparatus application, mobility was found in fewer number of miniscrews, but this difference was not statistically significant.

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