EVALUATION OF PEAK INSERTION TORQUE AND DIMENSIONAL CHANGES OF MINISCREW IMPLANT OF VARYING DIAMETERS IN DIFFERENT CORTICAL BONE THICKNESS

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CERTIFICATE

This is to certify that this dissertation titled **"EVALUATION OF PEAK INSERTION TORQUE AND DIMENSIONAL CHANGES OF MINISCREW IMPLANTS OF VARYING DIAMETERS IN DIFFERENT CORTICAL BONE THICKNESS"** is a bonafide record of work done by **DR.DEEPAK.C** under my guidance during his postgraduate study period between 2010–2013.

This dissertation is submitted to **THE TAMIL NADU Dr. M.G.R. MEDICAL UNIVERSITY**, in partial fulfillment for the degree of **Master of Dental Surgery in Branch V – Orthodontics and Dentofacial Orthopedics**. It has not been submitted (partially or fully) for the award of any other degree or diploma.

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CONTENTS

ABSTRACT

Aim: The purpose of this study was to evaluate the peak insertion torque of varying diameters of miniscrew implants in different cortical bone thickness and to assess the dimensional changes, distortion and fracture of the retrieved miniscrew implants. **Materials and Methods:** Seventy two self-drilling MSI's (SK company, India) of varying diameters (1.2mm,1.3mm,1.4mm and 1.5mm) were inserted into synthetic bone of different cortical thickness (1mm, 2mm and 3mm). The peak insertion torque values for each MSI were recorded. All the MSI's were retrieved and assessed for dimensional changes, distortion and fracture, both macroscopically and under scanning electron microscope. **Results:** The mean peak insertion torque recorded for the 1.2mm, 1.3mm, 1.4mm and 1.5mm were 7.02Ncm, 8.06Ncm, 10.02Ncm and 11.37Ncm respectively. The mean peak insertion torque recorded for the 1mm, 2mm and 3mm cortical bone thickness were 7.66Ncm, 9.06Ncm and 10.64Ncm respectively. The retrieved smaller diameter MSI's(1.2mm,1.3mm) showed, fatigue striations at the tips, threads and shaft core, blunting of the tips and threads, distortion and fracture at the thread shaft interface when inserted into thicker cortical bone(3mm). **Conclusion:** As the diameter of the MSI's and the cortical bone thickness increases, the peak insertion torque increases proportionately. When using a smaller diameter MSI's in dense cortical bone, a pilot drill will prevent the increase in the peak insertion torque and hence decrease the surface dimensional changes and improve the efficacy of the MSI's.

Keywords: Miniscrew implant, Cortical bone thickness, Peak insertion torque, Dimensional changes, Distortion, Fracture.

INTRODUCTION

Miniscrew implants (MSI) has received great attention in the orthodontic literature and among the orthodontists, because of its versatility, minimal surgical invasiveness, ease of insertion and removal, low cost, reliable three dimensional anchorage, and both for what they offer in theory as well as in clinical practice.

Primary stability is regarded as the key factor for MSI success. It varies according to individual patient, factors such as bone quantity and bone quality **(Motoyoshi et al, Wilmes et al)**[68,69,95] , implant site **(Wilmes et al)**[95, 96]**,** and MSI design **(Kim et al, Lim et al, Motoyoshi et al, Song et al)**[49, 69, 86]. Among all the factors the most important factors affecting the primary stability appear to be the cortical bone depth and its density. A positive relationship between cortical bone depth and insertion torque has been demonstrated in orthodontic literature **(Motoyoshi et al, Baumgaertal et al)** [2, 68]**.**

Insertion torque has been defined as the result of frictional resistance between the screw threads and bone. Miniscrew implant insertion torque reflects the amount of primary stability and is therefore considered as an important factor for the success of the anchorage mechanism **(Maria Nova et al)** [59]. Because of the variability's in the bone properties throughout the maxillo-facial complex, there is a variation in the mean MSI insertion torque values, which has been reported to be between 8.3Ncm in the maxilla and 10Ncm in the mandible **(Motoyoshi et al)** [68], it has been further suggested that the insertion torque should be higher than 8Ncm, but lower than 10Ncm for the long term clinical success of MSI **(Motoyoshi et al)** [69]**.** The subject-specific and the site-specific structural and mechanical properties of bone tissue can exhibit great variations in cortical bone thickness and density **(Baumgaertal et al, Park et al)**[2,75]**,** bone mineral content **(Choi et al)**[16]**,** and bone implant contact **(Buchter et al)**[7] which might affect the stability of the MSI. **Friberg et al**[32] reported that a low insertion torque increases the possibility of loosening of the MSI at the bone interface thus compromising the primary stability, while **Song et al**[86] suggested that excessive insertion torque over the range causes bone cracks and bone necrosis. Another probable consequence of excess insertion torque is failure within the miniscrew itself via its bending, fracture or its failure **(Philips et al)** [80]**.**

Fracture is one of the important risk factors and complications that may happen when using miniscrew implants. It normally occurs during insertion or removal, but can also happen during force application for orthodontic treatments **(Buchter et al 2005)**[7]. According to **Kravitz and Kusnoto et al**[50]**,** the most common reason for MSI fracture is due to increased torsional stresses that develops during its insertion. The bone quality and density can influence insertion torque resistance, and when associated to sub-perforation can increase incidence of fracture **(Maria Nova et al)**[59].On comparing the length, the diameter of the MSI has a stronger influence on the insertion torque and the dimensional changes or fracture risk of the MSI's.

Though helpful, MSI's are not without disadvantages or failures **(Carano et al)** [8]. While MSI manufacturers tout the advantages and positive characteristics of the products they sell, rarely are the mechanical properties and surface changes being outlined in their product guides. In spite of the adequate literature, many doubts still exist regarding how certain morphologic changes reflects the mechanical properties of MSI, consequently leading to dimensional changes, distortion and fracture, which are a potential risk. Therefore, when a clinician chooses an MSI for use in practice, he/she is presented with the difficult task of selecting which MSI will be best suited for each clinical situation.

However, there are not enough studies which has evaluated the effects of the dimensional changes of these MSI's when inserted into different cortical bone thickness and varying densities, so there is a need for evaluating such dimensional changes of MSI, at their tip, shaft, and head to know its mechanical limitations and to interpret their clinical applications.

The apparent void in the literature defining MSI performance in dense hard tissues suggests that clinicians are making assumptions about the strength of the MSIs that they have selected. There have been many studies on the mechanical properties of the MSI's , but they are hardly any reporting or interpreting the physical surface changes of these MSI's on insertion into various sites of varying cortical bone depth and its density. It is therefore important to investigate the mechanical limitations of these devices and interpret such findings.

Therefore the aim of our study was to **"EVALUATE THE PEAK INSERTION TORQUE AND THE DIMENSIONAL CHANGES OF MINISCREW IMPLANT OF VARYING DIAMETERS IN DIFFERENT CORTICAL BONE THICKNESS"**

REVIEW OF LITERATURE

Anchorage in orthodontics is the resistance to unwanted tooth movement. In the field of orthodontics, several methods have been developed to overcome the critical problem of anchorage. Among them, skeletal anchorage systems have gained increasing interest.

Currently, many MSI manufacturers exist yet they not all share the same design. MSIs are often described by four main characteristics:

1) the alloy or metal used;
2) the dimensions and design of the threaded portion, or shaft;
3) the screw head or attachment design, and
4) The insertion methodology.

Most of today's orthodontic miniscrews are fabricated from polished, bio-inert titanium alloys[3] (TiAl6V4) excepting the Orthodontic Mini Implant (Leone S.p.A.) which is fabricated from stainless steel. Though these alloys are usually classified as type IV or V titanium, orthodontic miniscrew manufacturers do not readily divulge their unique manufacturing information or material composition data.

The threaded portions of contemporary MSIs are engineered to be long enough to trespass soft tissues and gain anchorage in cortical and alveolar bone while also being narrow enough in diameter to avoid penetration or damage to tooth roots when placed adjacent to these structures. The design of the shaft is classified as cylindrical or tapered and the thread geometry is either symmetric or asymmetric.

Important to the interface between orthodontic anchorage devices and the orthodontic appliances is the head or attachment design—each varies from one manufacturer to the next but all are intended to facilitate the MSI's use as direct and/or indirect anchorage. Rectangular slots or bracket-head designs allow the orthodontist to use traditional rectangular wires as attachments while other head designs feature a circumferential recessed area around which a ligature attachment can be placed. MSIs may also include a hole in the neck or head through which a wire ligature can be passed in order to facilitate direct anchorage.

Insertion methods among MSIs may be categorized as either drill-free or nondrill-free, depending on the thread design. Drill-free MSIs feature a cutting tip which does not require that a pilot hole be created before insertion, while nondrill-free designs commonly require a soft-tissue punch and a pilot hole to be drilled in bone before placement.

While it is logical to assume that a certain combination of thread design, metal alloy, and/or dimension of the screw would be superior, this is not proven in the literature. The effects of implant length, diameter, shape, and design on insertion torque and pullout strength have been reviewed, but the mechanical limitations or the interrelationship between various diameters and cortical bone thickness on the insertion torque and dimensional changes of these MSI systems are not widely published.

Although miniscrew implants have had a reasonably high success rate, they are not devoid of limitations. Some of the common concerns among clinicians include risk factors for failure **(Cheng et al)**[15] and limitations of some placement sites **(Park et al)**[76]**.**

Anatomic location of bone parameters;

MSIs can be placed both in maxilla and mandible, but investigators have shown that placement site may influence their performance. Possible sites in the maxilla are the nasal spine, the palate, the infra-zygomatic crest, the maxillary tuberosities and the alveolar process. In mandible insertions have been reported in the symphysis, the alveolar process and the retro-molar area.

Berens et al[3] warned not to place MSIs in the lingual side of the lower jaw, due to the technical demand during insertion and the patients tongue interference and observed quite high loss rates on the palatal side of the upper jaw where according to them the mucosal thickness came into play. The palatal mucosa they reported is 5mm thick in some parts which automatically leads to a long lever arm, which is a decisive factor in the loss of the MSI. **Park et al**[76] on 227 MSI showed higher failure rate in the mandible (13.6% for the mandible and 4% for the maxilla). Other investigators could not identify a difference in failure rates between maxilla (15.9%) and mandible (16.4%) **(Miyawaki et al; Motoyoshi et al)** [65, 67]

Poggio et al[81] discussed that in maxilla, the best insertion sites are in the anterior and apical portion and in the mandible and the safest sites are between first and second molars and premolars. In the mandible the safest sites are mesial or distal to the first molar according to **Deguchi et al**[23]**.**

Cheng et al[15] said MSI in the posterior maxilla had longer survival than in the posterior mandible. MSI in the posterior versus anterior mandible were also prone to failure. This may be attributed to the higher susceptibility to infection in the posterior mandible, mainly because less attached gingiva is available in this region and higher bone density where overheating is more likely to occur**. Bernhart et al**[4] stated that in palate, the mid-palate, and 3 to 6 mm to the paramedian region offer sufficient bony support.

Cortical bone thickness (CBT) and density can vary according to the region of placement. Areas with thick cortical bone are considered the most stable for MSI placement. Since retention depends essentially on the bone-metal interface, the greater the bone, the better the primary stability. On the other hand, the higher the bone density the greater the bone pressure and bone damage during insertion. **Baumgaertel et al**[2] found that CBT decreased from anterior to posterior palate and recommends a placement site in premolar region. The same holds for **Kang et al**[46] who found that the midpalatal area within 1 mm of the midsagittal suture had the thickest bone available in the whole palate. The thickness tended to decrease laterally and posterior. So, when a MSI could deviate from the midpalatal area by more than 1 mm, they recommend placing it not far posterior or using a shorter MSI.

The above studies show that there is evidence that cortical bone thickness (CBT) can have strong influence on primary stability of MSIs. **Motoyoshi et al**[67] **and Motoyoshi et al**[67] found in both studies that success rates in the groups with CBT ≥ 1 mm were significantly higher than those in the groups with CBT ≤ 1 mm. Inter-dentally cortical bone thickness varies in the upper and lower jaw and a distinct pattern appears to be present. The knowledge of this pattern and the mean values of thickness can aid in MSI site selection and preparation.

Miniscrew Implant Related Factors:

Differences have been reported between conical and cylindrical shaped MSIs regarding their retention in bone, with the first ones tending to be in an advantageous position. The conical MSIs show greater primary stability compared to the cylindrical ones as found in a study of **Wilmes et al[94].** He compared the Dual Top MSI and the Tomas pin and found that despite having the same dimensions the Tomas pin types showed less primary stability than the Dual Top MSI. One apparent reason for that is the intra-osseous part of the Tomas pin which is cylindrical, which seems inferior to those having a conical shape.

Kim et al[47] (2008) showed in his mechanical study that the conical group of MSIs showed significantly higher maximum insertion torque (MIT) and maximum removal torque (MRT) than the cylindrical group. He concludes that although the conical shaped MSI could induce tight contact to the adjacent bone tissue and might produce good primary stability, the conical shape may need modification of the thread structure and insertion technique to reduce the excessive insertion torque while maintaining the high resistance to removal

Kim et al[49] (2009) compared cylindrical, taper shaped and dual thread MSIs and said that the cylindrical shape had the lowest MIT and MRT in each length. Although taper shape showed the highest MIT in each length, when the values of insertion and removal angular momentum were analysed (IAM and RAM), dual-thread shape showed significantly higher MRT and RAM in each length. Dual-thread groups showed a gentle increase of insertion torque and a gentle decrease of removal torque in contrast to the other shape groups. He concluded that dual-thread shape provided better mechanical stability with high removal torque on the broad range than other shapes. However, due to their higher IAM and time of MIT they need improvement to reduce the long insertion time to decrease the stress in the tissues.

Miniscrew Implant Dimensions:

MSI dimensions are referred to MSI length and diameter. The influence of these two parameters on MSI stability is still under investigation and studies seem to be controversial.

Miniscrew Implant Length:

Hitchon et al[38] (2003) examined the effects of MSI length (12 mm, 14 mm and 16 mm) by testing 201 MSI-type MSIs in fresh human cadaver specimens. Length was shown to have a statistically significant effect on pull out strength, with longer MSI having a higher resistance to displacement. This might be expected because holding power is directly proportional to the amount of thread engagement as reported by **Lyon et al[58] (1941).**

Fritz et al[30] (2003) reported that 4 mm long MSI offer adequate stability when compared with 6 mm and 8 mm MSI. **Miyawaki et al[65]** do not associate the length of the MSI with its stability if the MSI was at least 5 mm long. Also **Cheng et al[15] and Park et al[76]** agree with the above mentioned authors. The short MSI used for the fixation did not jeopardize the performance; this means that longer MSIs did not necessarily result in greater bone support as stated by **Park et al**[76]**.**

On the contrary, **Tseng et al**[88] **(2006)** stated that the length of the inserted MSIs was an important risk factor. They emphasize that the actual depth of insertion of the MSI was more important than its length, the recommended length being at least 6 mm. This is in accordance with dental implantation, where **Winkler et al**[97] stated that the shorter and smaller diameter MSIs had lower survival rates than their counterparts.

Chen et al[14] **(2006)** studied, retrospectively, the relationship between MSI length and the retention rate. Fifty-nine MSIs, either 8 mm or 6 mm in length, with a diameter of 1.2 mm, were placed in 29 patients for orthodontic anchorage. A statistically significant difference was found between the two groups. The success rates of the 8 mm MSIs and 6 mm MSIs were 90.2% and 72.2%, respectively. Also, other studies by **Park et al**[76]**, Kuroda et al**[51] have also shown higher success rates by increasing the length of the MSIs with the same diameter, but the differences were not statistically significant.

Lim et al[56] **(2008)** examined the effects of MSI length, diameter and shape on insertion torque. Cylindrical and taper type MSIs with different lengths, diameters, and pitches were tested by placing them in synthetic bone. Their results showed that increasing MSI length resulted in greater insertion torque, suggesting that greater stability could be achieved.

Miniscrew Implant Diameter:

Ohmae et al[72] (2001) showed that MSIs, 1 mm in diameter and 4 mm in length, placed in the mandibular third premolar region of beagle dogs were able to sustain an intrusive force of 1.5 N for 12 to 18 weeks.

However, **Miyawaki et al[65] (2003)** thought that the diameter of the MSI was significantly associated with their stability. They later reported that 1 year success rate of MSI with a 1 mm diameter was significantly less than that of MSI with diameters of 1.5 and 2.3 mm. They also found that patients with a high mandibular plane angle showed a significantly lower success rate than those with an average or low angle. This could be attributed to the fact that the thickness of buccal cortical bone in subjects with high mandibular plane angle was thinner than that in subjects with a low angle in the mandibular first molar region. They concluded that the wider MSI should be especially placed in patients with vertical facial growth.

Cheng et al[15] (2004), states that MSI types of identical configuration show no difference in their success. **Carano et al[9]** have suggested that MSI smaller than 1.3 mm should be avoided, especially in the thick cortical bone of the mandible**.**

A study of **Berens et al[3] (2006)** found that MSI of a diameter of 2 mm in lower jaw increases success rate. They also recommend a MSI diameter of at least 1.5 mm in the palatal upper jaw. **Wilmes et al[95] and Lim et al[56]** reported that MSI with 2 mm diameter showed significantly higher insertion torque when compared with MSI with a 1.6 mm diameter.

<u>Miniscrew Implant Core Diameter:</u>

Minor diameter refers to the inner (or core) diameter of MSIs which can range anywhere from 1.2-1.6 mm. Inner diameter has been reported to be one of the important factors determining pull out strength because the maximum torsional shear strength of the MSI is related to the cube of its diameter; tensile strength corresponds to the square of its diameter. **Huges et al[39] (1972)** reported that minor diameter is also important because the strength of the MSI is directly related to it.

Decoster et al[22] (1990) showed that minor diameter had a negative effect on pull out force, with an increase in minor diameter leading to a decrease in pull out force. Increasing the minor diameter from 4 mm to 5 mm decreased the mean pull out force from 277.8 lbs to 247.8 lbs

Carano et al[9] (2005) studied the mechanical properties of three commercially available self-tapping MSIs. They suggested that a minor diameter reduction of as little as 0.2 mm can reduce the resistance to breakage of the MSI by 50%. An overall minor diameter of less than 1.5 mm was not recommended for orthodontic applications because humans can apply enough torsional forces to break smaller MSI. However, if placement torque could be reduced through the addition of other design features, it is theoretically possible to further reduce MSI size.

<u>Miniscrew Implant Outer Diameter</u>

The orthodontic literature does not contain much information on the effect of outer diameter of MSI on primary stability. However, the orthopaedic literature shows that outer MSI diameter is one of the most important variables in mechanical strength. MSI with greater outer diameter show greater primary stability due to greater surface area in contact with the bone.

Hughes et al[39] (1972) recommended using MSI with a larger outer diameter when greater holding power is desired. The major diameter is the diameter as determined by the outer diameter of the threads. Outer diameters vary widely among and within different manufacturers. MSIs currently available in the market have outer diameters ranging between 1.2 mm and 2 mm. Various diameters of MSIs have been reported to be successful in providing anchorage. There is indirect evidence indicating that outer diameter is important for stability.

DeCoster et al[22] (1990) used a synthetic bone model to determine the maximum bone-MSI pull out force of orthopaedic MSI with various outer diameters. As the major diameter was increased, within a range of 3-6 mm, the mean pull out force also increased in a roughly linearly fashion from 105.4 lbs to 305.8 lbs. Increasing the outer/inner diameter ratio, while holding the other parameters constant resulted in a small, but significant, increase in pull out force.

Miyawaki et al[65] (2003) all reported that the 1.0 mm outer diameter screws failed, while the 1.5 mm and 2.3 mm diameter screws showed success rates of 83.9% and 85%, respectively. The authors concluded that a diameter of less than 1.0 mm was a significant criterion associated with failure. The advantage of a thinner screw is that it can be placed in more locations, such as between the roots of teeth. The drawback, however, is the greater potential for screw fracture **.**

Wilmes et al[95] (2008) studied various parameters affecting the primary stability of orthodontic MSIs. Outer diameter was one of the parameters determined to have an influence on primary stability. Insertion torques of five different MSI types, tomas-pin (Dentaurum, Ispringen, Germany) 08 and 10 mm, and Dual Top (Jeil Medical Corporation, Seoul, Korea) 1.6 × 8 and 10 mm plus 2 × 10 mm, were measured to determine their primary stability. The Dual Top MSI with a diameter of 2 mm achieved the greatest primary stability followed by the Dual Top MSI with a smaller diameter of 1.6 mm. It has been shown that various MSI factors such as MSI diameter, (**Morrarend et al[66]**, **Lim et al[56]**) MSI length (**Park et al[76], Crismani et al[20]**), pitch and flutes,(**Brinley et al[5]**)are all important determinants of holding power.

Eventhough there are adequate literature on the effect of various diameters on the primary stability of the MSI'S, but there are no studies which defines the mechanical limitations of selecting various diameters of MSI's for sites of varying cortical bone thickness .

<u>Testing primary stability</u>

The various methods available to test implant stability can be divided into invasive and non-invasive methods. The noninvasive methods include percussion testing, radiographic methods, resonance frequency analysis and placement torque **Meredith et al[62] (1998)**.

Various techniques have been used to test the primary stability of endosseous implants. It is highly desirable to have a quantitative method for establishing primary implant stability at the time of placement. When analyzing primary stability, one has to ensure that no bone remodeling has occurred.

Various invasive methods are also available to assess the implant-tissue interface after implant placement. Invasive methods to measure implant stability are all destructive in nature and, consequently, can only provide cross-sectional data at one point in time. This limits their usefulness in understanding the healing process and in appreciating its relationship with stability.

One invasive method used to evaluate primary stability measures cutting torque resistance.This technique measures the energy needed to remove bone prior to implant placement. **Friberg et al[32] (1999)** showed a positive correlation between cutting torque resistance and bone density, which is one of the factors that determines stability. The limitation of this method of measurement is that repeated measures cannot be made; it is only useful to estimate the implant stability prior to placement. It is used most frequently for prosthetic dental implants where the larger size of the implant necessitates the removal of bone prior to placement. Bone removal prior to placement of orthodontic mini-screw implants is often not needed due to their small size. This factor also limits the importance of this method for orthodontic applications.

As such, tests are typically performed during or immediately after implant insertion **Huja et al[40] (2005)**. In situations where non-viable tissues are being tested, primary stability can be measured at any time. For the analysis of primary stability, insertion torque is perhaps the best and most commonly used method.

Insertion torque of Miniscrew Implant:

Insertion torque (IT) is the result of frictional resistance between MSI threads and bone. Axial pull out strength (PS) reflects the magnitude of the PS that the MSI bears before bone rupture. Both methods have been used to determine MSI retention in the bone. A correlation between IT and PS was found by many authors even though other studies concluded that this correlation does not exist.

Bowman et al[6] reported that the force used to insert the MSI is transferred through the screw and produces a compressive force on the adjacent bone. A minimal level of insertion torque is required to achieve an adequate amount of stability. However, too much torque during placement may cause damage to the adjacent bone and eventually result in screw failure.

Insertion torque is an objective method of measuring implant stability that was originally introduced by **Hughes and Jordan[39](1972).** This is probably the most often used method to evaluate primary stability. It describes the rotational force required to insert a screw into bone **Collinge et al[19] (2000)**.

Hughes et al[39] (1972) reported that during implant placement, the torsional forces are low as the screw threads are first engaged and inserted through the cortex. The force levels increase and peak once the entire cortical layer is engaged. Insertion torque increases rapidly and reaches a maximum value upon screw head contact. The countersink friction, which is the contact of the screw head with the bone, creates this peak in insertion torque. After this point, insertion torque will decrease as the screw or bone fails under shear stress. The material surrounding the threads becomes stripped and the screw eventually spins freely in the hole.

Collinge et al[19] (2000) described the insertion torque as the rotational force required to insert a screw into a bone.

O'Sullivan et al[71] (2004) reported that insertion torque values differ according to MSI type and higher values of insertion torque show higher interfacial stiffness at the MSI-bone interface. Placement torque correlates directly with cortical bone thickness. Other aspects influencing IT are the bone quality and quantity, the drilling hole, MSI characteristics and insertion technique, continuous or intermittent rotation and dry or wet conditions.

Insertion torque is said to determine primary stability (**Deguchi et al[23], Wilmes et al[94]).** And as known, a sufficient primary stability measured by insertion torque seems to play a major role for the treatment time survival rate **(Motoyoshi et al)[68].** This is also proven in dental implantology. Insertion torque levels must range between certain limits, since very low or very high values can be critical for MSI success.

Motoyoshi et al[67] (2006) reported higher loss rates when the insertion torque exceeds 10 Ncm for MSIs with a diameter of 1.6 mm. A torque value of more than 15 Ncm recorded at the time of insertion appears to be one of the critical variables for MSI survival under immediate loading according to **Chaddad et al[12].** The high torque values may result in higher failure rates due to bone compression, local ischemia, necrosis and micro damages **(Wawrzinek et al)[91].**

Cleek et al[18] (2007) reported that with increasing torque, microdamage may accumulate in the bone surrounding the implant, leading to a reduction of bone holding strength. Another probable consequence of excess insertion torque is failure of the miniscrew itself via its bending or fracture

<u>Factors Influencing MSI Insertion Torque</u>

As early as 1968, **Ansell and Scales[1]** identified a handful of factors which, though applied to surgical screws, are applicable to MSIs and are thought to influence the amount of torque exerted during insertion: bone quality, pilot hole size, thread design, and insertion methodology. During the process of removal, intimate contact between bone and MSI (also known as secondarystability or partial osseointegration) may also contribute to excess torsional strain**(Carano et al 2005)[9]**

High insertion torque and the resulting compression of bone, though proven to be helpful in providing primary stability[29,64,67]**,** can also cause microfractures or ischemia in the surrounding hard tissue. Such trauma may lead to a disruption of microcirculation in the bone, and in turn a destruction of osteocytes. **(Matsuki et al, Meredith et al)**[61,62]. Conversely, lower insertion torque may contribute to suboptimal primary stability allowing for micromotion in dynamically-loaded implants and consequently failure to achieve secondary stability.

Surface characteristics Of Miniscrew Implant:

The surface of the intra-osseous part of MSI is mostly treated mechanically, but there are also cases where sandblasting and acid etching is performed. Mechanical and surface treatments seem to provide better Osseo-integration and can help to increase their stability. The preference between a large-grit sandblasting and acid etching (SLA) or a mechanical preparation depends on the desired clinical outcome of MSIs, since the type of surface preparation is seemed to influence the degree of Osseo-integration.

Chaddad et al[12] **(2008),** in a study on the success rates of surface treated MSIs, surface characteristics did not appear to influence survival rates of immediate loaded MSIs. However, **Kim et al**[47] **(2009a)** stated that the maximum insertion torque value and insertion angular momentum were significantly lower in the SLA group than in the machined group, but showed higher removal energy, indicating that SLA surface treatment had influenced the Osseo-integration potential

Patient-related factors such as age and gender seem not to influence success rates in most publications, although in one study where computed tomography was used measured cortical bone was thinner in females in the attached gingiva mesial to the maxillary first molar. Physical and dental status such as osteoporosis, uncontrolled diabetes, periodontal disease, smoking and pharmacologic prescriptions such as biophosphonates are considered risk factors for classic dental MSIs. It is probably wise to avoid the use of MSIs in these patients **(Reynders et al, 2009)[82].**

Soft tissue characteristics are also an MSI maintenance related factor. The necessity of peri-MSI keratinized mucosa for the maintenance of MSI health has long been a debatable issue for endosseous dental MSIs. However, retrospective clinical surveys have failed to reveal major differences in the survival of MSIs placed in keratinized or non- keratinized mucosa. **Warrer et al (1995)[90]** discovered that absence of keratinized mucosa around endosseous MSIs increased the susceptibility of the peri-implant region to plaque induced tissue destruction. This is in accordance to the findings of **Cheng et al[14] (2004)** who found that absence of keratinized mucosa around MSIs significantly increases the risk of infection and failure.

Bone Related Factors In Maxilla And Mandible:

Bone has a significant influence on miniscrew stability. There are various bone factors that affect stability during primary and secondary phases. Bone density, quality and the thickness of the cortex have been found to affect primary stability and correlate with insertion torque and pullout strength.

Thickness of cortical bone

Cortical bone thickness, which is measured with the help of insertion torque and pull-out strengths, is another one of the most significant factors determining primary stability and consequently playing an important role in the success or failure of the MSI. is another one of the most significant factors determining primary stability. Areas with thick cortex are considered to be better for miniscrew placement. **(Miyawaki et al, Huja et al)**[65,41`]**.**

Ansell et al[1] **(1968)** reported retention depends on the bone-to-screw contact, better bone quantity should result in better primary stability

Huja et al[41] **(2005)** performed pull-out tests by placing 56 MSIs in the maxilla's and mandibles of beagle dogs. They found a positive correlation between cortical bone thickness and the maximum force at pull-out (Fmax). Fmax was reported to be 134.5 N in the anterior mandible and 388.3 N in the posterior regions of the mandible. They also showed that the posterior regions of the jaws had thicker cortical plates and greater pull-out values. In another study, **Huja et al**[40] **(2006),** found peak pull-out strength to be directly related with cortical bone thickness at 6 weeks post-insertion in a canine model.

Dalstra et al[21] showed that the maximum stress occurs at the cortical bone level when an implant is loaded. Using a finite element model, they showed that increasing cortical bone thickness drastically reduced the peak strain development in the peri-implant bone tissue. This inverse relationship between cortical bone thickness and peak strain development suggests that cortical bone thickness is a key determinant of initial stability.

Motoyoshi et al[67] recommend that the prepared site should have a cortical bone that is more than 1.0 mm thick. They stated that individuals with greater MSI success had significantly higher cortical bone thickness. Cortical bone thickness and insertion torque were significantly greater in the mandible than in the maxilla.

In orthopaedics, **Cleek et al[18] (2007)** studied the effects of cortical bone thickness on pull-out strength. Their data showed that pull-out strength was significantly correlated with cortical thickness (r = 0.56, p = .002).

Salmoria et al[84] found that cortical bone thickness had a direct effect on pull-out strength. They measured pull-out strength and cortical bone thickness at the time of placement and 60 days after placement. After 60 days, both the thickness of the cortical bone and the pull-out strength had decreased. Bone had resorbed around the neck of the MSI. They concluded that there was a correlation between axial pull-out strength and cortical bone thickness.

Salmoria et al (2008)[84] in his study reported that cortical thickness is one of the main factors influencing insertion torque and, consequently, primary stability and failure rate. More screw threads are able to engage into thicker cortical bone which, in turn, translates into greater primary stability.

Bone mineral density

As a method for classifying bone quality, **Lekholm et al[54] (1985)** categorized the jaws into Q1 to Q4 according to bone quality using the ratio of cortical to spongy bone as follows: Q1, almost the entire jaw is composed of homogenous compact bone; Q2, a thick layer of compact bone surrounds a core of dense trabecular bone; Q3, a thin layer of cortical bone surrounds a core of dense trabecular bone with favourable strength; and Q4, a thin layer of cortical bone surrounds a core of low-density trabecular bone.

Misch et al[63] (1990) classified bone density into 4 categories based on the hardness of compact and spongy bone as follows: D1, dense compacta; D2, thick porous compacta and coarse trabecular; D3, porous compacta and fine trabecular; and D4, fine trabecular. They suggested a treatment plan according to each classification. Generally, D1 bone might be located in the lower anterior or posterior regions but is quite rare. D2 bone is common in the mandible at approximately two thirds of the lower anterior, approximately half of the lower posterior, and approximately one fourth in the maxilla. D3 bone is common in the maxilla at approximately half of the upper posterior, approximately 65% of the upper anterior, approximately 23% of the lower anterior, and almost half of the lower posterior. D4 bone is found in the maxillary posterior. On the other hand, bone density is strongly related to bone strength; the compressive strength of bone is proportional to the square of density **(Carter et al, Rice et al)[11,83].**

Torque in Relation to Clinical Success

Given the pros and cons of insertion torque and its relationship to primary stability and bone biology, **Motoyoshi et al[67]** sought to investigate clinically whether an “adequate implant placement torque” exists wherein the highest success rate could be achieved. A total of 124, 1.6 mm diameter X 8 mm long, tapering-style orthodontic MSIs (BIODENT Co. Ltd, Tokyo, Japan) were placed in 41 patients by first drilling a pilot hole 1.3 mm wide and 8 mm long, and immediately loaded. This study indicated that success rates were highest for those with implant placement torque within the range of 5 to 10 Ncm.

Wilmes et al[95] advised limiting insertion torques to a maximum of 20 Ncm and stated: If the aim is to achieve high insertion torques on the one hand and prevent implant fractures on the other, one must determine the ideal combination of pre- drilling depth, pre-drilling diameter, and implant according to the insertion region and bone quality. Notwithstanding the research describing these attributes of implant success and stability, the risk of fracture remains. The percentage of practicing orthodontists who are aware of this inherent risk is great.

Failure rates and understanding MSI failure ;

Loss of miniscrew stability limits their usefulness. The ultimate cause of implant failure is a lack of bone-toimplant contact. A number of factors have been suggested as possible reasons for implant loss. Peri-implantitis when inserted in the unattached mucosa, **Cheng et al**[15] **(2004)** application of excessive forces on the miniscrew implant, **Buchter et al**[7] **(2005))** insufficient primary stability,**Motoyoshi et al**[67] **(2006)** bone damage during insertion due to compression or over-heating, **Wilmes et al**[95] **(2006)** and excessively large lever arms (thick mucosa), **Wiechmann et al**[93] **(2007)** , are just some of the implicated factors.

Failures can be subdivided into the host factors, the surgical technique or the management of the miniscrew during treatment. While it is not clear how host factors affect the long-term stability of MSIs, their effects have been established for endosseous implants.

In a retrospective evaluation of clinical cases, **Cheng et al**[15]. reported miniscrew success rates of 89%.16 Peri-implant soft tissue characteristics and anatomic location were identified as two independent prognostic indicators of the MSI failure. Lack of keratinized mucosa increased the implants' susceptibility to plaque induced tissue destruction. An association was found between peri-implant infection and a high rate of implant loss. Implants placed in the posterior mandible also demonstrated greater failure rates, which were thought to be due to lesser amounts of attached gingiva in the posterior region. Overheating, due to the increased density of bone in the mandibular posterior region, was also thought to be a cause of failure rates. Another retrospective study of treated cases performed by Park et al. reported an overall success rate of 91.6%.31 Mobility of the miniscrew, miniscrews placed in the mandible, inflammation of the gingiva around the screw, and miniscrews placed in the right side were some of the factors identified as increasing the risk of MSI failure. They noted that minimally mobile miniscrews can be maintained when the applied force is light. While mobility does not represent failure, it does increase the risk of failure. They further noted that if heavy forces were applied, the mobility may be increased; increases in osseous microfracture and bone trauma can occur and lead to failure when heavy forces are applied.

Miniscrews in the mandible demonstrate greater failure rates than MSIs placed in the maxilla, possibly due to its greater density and the increased potential of irritation during mastication.24 The mandible's greater density can lead to more drilling, which could cause overheating. Heat greater than 47°C may cause bone necrosis.

Miyawaki et al[65] suggested that factors associated with failure were the implant's diameter, inflammation of the peri-implant tissue and the mandibular plane angle.32 They found that screws with 1.0 mm diameters had success rates of 0%, but screws with 1.5 mm and 2.3 mm diameters had success rates of 83.9% and 85%, respectively. They also showed that patients with high mandibular plane angles tended to have thinner buccal cortical bone and may lack sufficient mechanical interdigitation. Inflammation can increase the risk of miniscrew failure due to bone damage around the neck of the MSI. Over time, inflammation may lead to progressive loss of bone. This could cause the screw to lose its mechanical grip and fail. Park et al. attributed the greater success of miniscrews placed on the left than the right side to the fact that the majority of the patients were right-handed and might be expected to have better hygiene on the left side. Better hygiene results in less inflammation and possibly promotes greater success of miniscrew stability. It, thus, becomes imperative to gain an understanding of the MSI stability and the factors determining it.

<u>Prevalence and Incidence of Fracture</u>

The literature does not regularly cite MSI fracture data in clinical orthodontics but oftentimes the data is incidental. Research in animal and bench-top study models have also shed some light on the frequency of MSI fracture.

In **2005, Buchter and colleagues**[7] placed a total of 200 mini-implants (102 AbsoAnchors with dimensions 1.1 mm X 10 mm and 98 Dual-Top 1.6 mm X 10 mm) in the mandible of eight minipigs and found that six AbsoAnchor and two Dual-Top MSIs fractured upon insertion while one AbsoAnchor and one Dual-Top MSI fractured during the removal torque test. These figures represent an average 4 percent and 1 percent incidence of fracture upon insertion and removal respectively.

In **2006, Park and colleagues**[75] conducted research to identify the factors associated with the clinical success of MSIs and reported that 8 of 227 (3.5 percent) implants fractured during testing among 87 consecutive patients. Three screws fractured during placement and five fractured during removal (seven Osteomed, Addison, TX, and one KLS-Martin, Jacksonville, FL).

In **2006, Wilmes et al**[95] reported nine fractured Dual-Top screws of 2.0 mm diameter and 10 mm length when using the ileum of country pigs as a bone model. The total number of tested Dual-Top MSIs was not reported.

In **2008, Mischkowski et al**[64]. observed that 9.5 percent of the tested Dual-Top MSIs (2 mm x 10 mm) fractured at insertion torques ranging from 52 to 56 Ncm when placed into bovine femoral heads. As recently as **2010, Florvaag et al**[29] used a similar testing medium and demonstrated a 5 percent incidence of fracture using MSIs of various dimensions (1.6 to 2.0 mm X 8 to 10 mm). Findings such as these are not unique to orthodontic MSIs. Surgeons alike have reported that bone screws placed in the mandible require greater seating torque and there is an increased risk of small bone screws fracturing.\

Though fractures appear to be infrequent, simply knowing that MSIs occasionally fracture is enough to warrant further investigations characterizing those risks. One factor which may prove beneficial to understand is the range of torque values and their interrelationships with dimensional changes of these MSI's on insertion into bones of varying cortical bone thickness, which a clinician should know before he/she selects a MSI for clinical purpose.

Summary and Statement of Purpose

While the success of MSIs as anchorage is generally accepted and the incidence of fracture appears to be low, an understanding of the mechanical limits of MSIs and its dimensional changes become important when placed in dense bone or thick cortices. One must be confident that the torque necessary to insert an orthodontic miniscrew are well below the fracture range of the same.

Carano et al[9] emphasized that "comparative studies on the mechanical properties of screws fabricated from different materials of different dimesions designed with different geometry or constructed by different manufacturers inserted into different regions of varying bone properties could be important for clinical application in orthodontics." Such a study is the purpose of this research.

MATERIALS AND METHODS

The present In-Vitro study was carried out in the Department of Orthodontics and Dentofacial Orthopaedics, Ragas Dental College and Hospitals, Chennai.

MINISCREW IMPLANTS:

Seventy two miniscrew implants were chosen and used in this study (SK Company**).** All MSI's had standardized 6mm lengths and varying diameters of 1.2mm, 1.3mm, 1.4mm and 1.5mm**.** All the MSI's selected in this study were self-drilling and tapered. **(Fig 1, Table 1)**

Length, diameter and thread type of the MSI's Tested

MSI's tested	Diameter	Length	Thread type
SK company (ind)	1.2mm	6mm	Tapered
SK company (ind)	1.3mm	6mm	Tapered
SK company (ind)	1.4mm	6mm	Tapered
SK company (ind)	1.5mm	6mm	Tapered

SYNTHETIC BONE MODEL

In this study artificial bone made of polyurethane **(Sawbones Division of Pacific Research Laboratories, Vashon Island, Washington)** was selected because it met the requirements of the American Society for Testing and Materials (F-1839- 08) and has been successfully used for biomechanical tests of bone screws. The fiber filled epoxy sheets and solid rigid polyurethane foam were used as alternate experimental materials for cortical and cancellous bones respectively**(Ta ble 2,3) (Fig 2).**The bone blocks selected had three combinations of varying cortical bone thickness of 1mm, 2mm, and 3mm respectively. Each artificial bone block used in the study was custom-made by the company having 120 x 170 x 41mm dimensions **(Fig 3)** with different cortical bone thickness of 1mm, 2m, 3mm and density of 30pcf (pounds per cubic foot) **(Table 4)**.Each bone block was then cut into rectangular blocks of 30 X 40 X 120mm each, for the ease of insertion and testing in the custom made apparatus**.**

CUSTOM-MADE ALUMINIUM APPARATUS FOR MEASUREMENT OF INSERTION TORQUE:

To quantify the insertion torque during MSI placement procedure, an aluminum apparatus was custom made for this study **(Fig 5).** This apparatus consists of a torquimeter driver guide **(Fig 5)** which allowed placement of the digital torque driver (Lutron TQ8800; Taiwan**) (Fig 4)** which measured the insertion torque. The torquimeter driver guide allowed forward and backward movement of the digital torque driver in horizontal direction, which prevented wobbling or oblique forces during MSI insertion. The digital torque driver consisted of a torque sensor which minimizes the reading error. The apparatus also consisted of a slider with a clamp **(Fig 5)** which stabilized the bone blocks in its position before each MSI was inserted.

PROCEDURE FOR EVALUATION OF INSERTION TORQUE:

Each MSI head was held snugly in the digital torque driver with the help of an inbuilt chuck, which stabilized the MSI perpendicular to the artificial bone surface prior to its insertion at a pre-determined point **(Fig 6).** MSI's were inserted using finger pressure in a clockwise rotational axis, to simulate the clinical situation. **(Fig 7)** It was determined from previous studies that finger pressure produced approximately five pounds (5.11 lbs, 2.318 kg), which is adequate to advance the MSIs into the synthetic bone. **(Carono et al)** [10]

All the MSI's were inserted in a horizontal direction unlike axial direction which prevented any unwanted force. Since all the MSI's were of self-drilling type, no pilot holes were drilled. Each MSI tip was placed perpendicular to the artificial bone blocks. The MSI's were inserted to a depth of 6mm, until the head contacted and compressed the artificial bone surface to obtain true measurement of peak insertion torque values **(Fig 8).** During insertion, finger pressure was applied to the digital torque driver's rotational axis to provide adequate perpendicular force for the MSI's to perforate the cortical bone. For each cortical bone thickness(1mm, 2mm and 3mm) , twenty four MSI's of varying diameters(1.2mm, 1.3mm, 1.4mm and 1.5mm) were inserted . Final peak insertion torque of each MSI was recorded in Newton centimeters (Ncm) using digital torque driver **(Lutron TQ8800).** The maximum torque reached before fracture of the mini-implant was also recorded in Ncm. If the miniscrew implants did not fracture, their peak insertion torque values were recorded in Ncm. After evaluation of peak insertion torque values for each diameter of MSI's, all the MSI's were retrieved for evaluation of dimensional changes, distortion and fracture.

PROCEDURE FOR EVALUATION OF DIMENSIONAL CHANGES

To evaluate the dimensional changes, distortion and fracture, MSI's were retrieved passively in an anti-clockwise direction using a digital torque driver. All the MSI's were evaluated both macroscopically and under scanning electron microscope.

MACROSCOPIC EVALUATION:

All the retrieved MSI's were evaluated macroscopically for dimensional changes, distortion and fracture of the miniscrew implants at the tip, threads and shaft core. **(Fig 9)**

SCANNING ELECTRON MICROSCOPY (SEM) SCAN;

Photomicrography

The miniscrew implants were mounted on special aluminum bases using a double face carbon sided tape. Miniscrew implant topography were examined and photographed under a HITACHI, S3000N Scanning Electron Microscope (SEM) (Hitachi, Tokyo, Japan) **(Fig10)** at high vacuum ($5.1\text{-}10^{-6}$

Pa) operated at 0.3 to 30Kv acceleration voltage. Each miniscrew was examined for signs of dimensional changes, distortion and fracture site at various magnifications. Special attention was given to the tip of the miniscrew implant, threads, and shaft core which were observed at 10x and 50x magnifications. Digital images were acquired by Scanning Electron microscope (SEM). The photomicrographs obtained were evaluated for dimensional changes of different diameters of MSI's on insertion into varying cortical bone thickness.

STATISTICAL ANALYSIS:

Data entry and statistical analysis was performed with using the SPSS v.17 (SPSS Inc., Chicago, Illinois, USA).Descriptive Statistics was done for evaluating the peak insertion torque values of varying diameters and different cortical bone thickness. Descriptive statistics were done to find the range, mean, standard deviation of insertion torque. To evaluate the significance of the individual parameters such as the diameter and the cortical bone thickness, influencing the peak insertion torque values, a One Way ANOVA Test with 95% confidence interval was performed. For multiple comparisons within the parameters, the Post-hoc test (BONFERRONI) was done. A P value less than or equal to 0.005 was taken as significant.

Table 1- Mechanical properties of synthetic bone block

DENSITY		COMPRESSIVE		TENSILE		SHEAR	
		STRENGTH	MODULUS	STRENGTH	MODULUS	STRENGTH	MODULUS
Pcf	g/cc	Mpa	Mpa	Mpa	Mpa	Mpa	Mpa
30*	**0.5**	**18**	**445**	**12**	**592**	**7.6**	**87**

Table 2- Mechanical properties of epoxy sheet

DENSITY g/cc	LONGITUDINAL TENSILE		COMPRESSIVE	
	STRENGTH	MODULUS	STRENGTH	MODULUS
	Mpa	Gpa	Mpa	Gpa
1.64	106	16	157	16.7
	TRANSVERSE TENSILE			
	STRENGTH	MODULUS		
	MPa	GPa		
	93	10		

Table 3- Different thickness of cortical bone and density

CORTICALBONE THICKNESS	DENSITY
1mm	30 pcf
2mm	30 pcf
3mm	30 pcf

Fig 1- Varying diameters of MSI's

(1.2mm, 1.3mm, 1.4mm and 1.5mm)

Fig 2- Synthetic bone block with fiber filled epoxy sheets and solid rigid polyurethane foam as alternate experimental materials for cortical and cancellous bones respectively

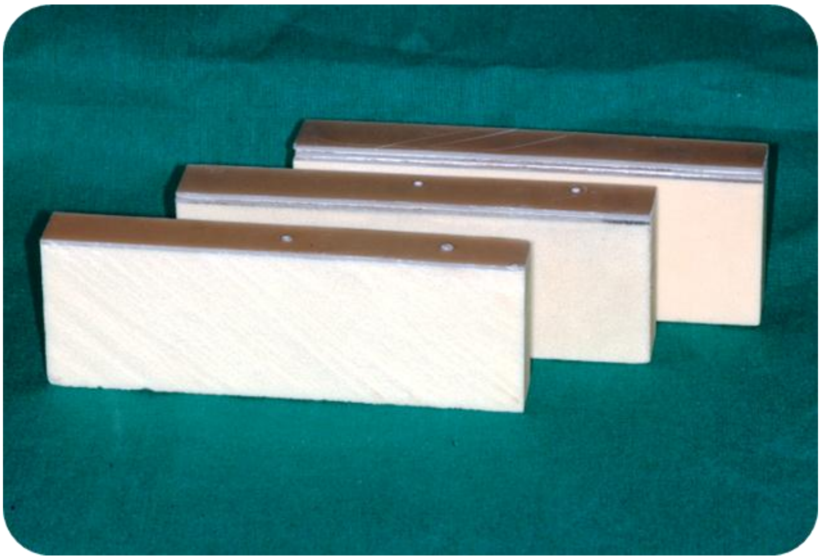
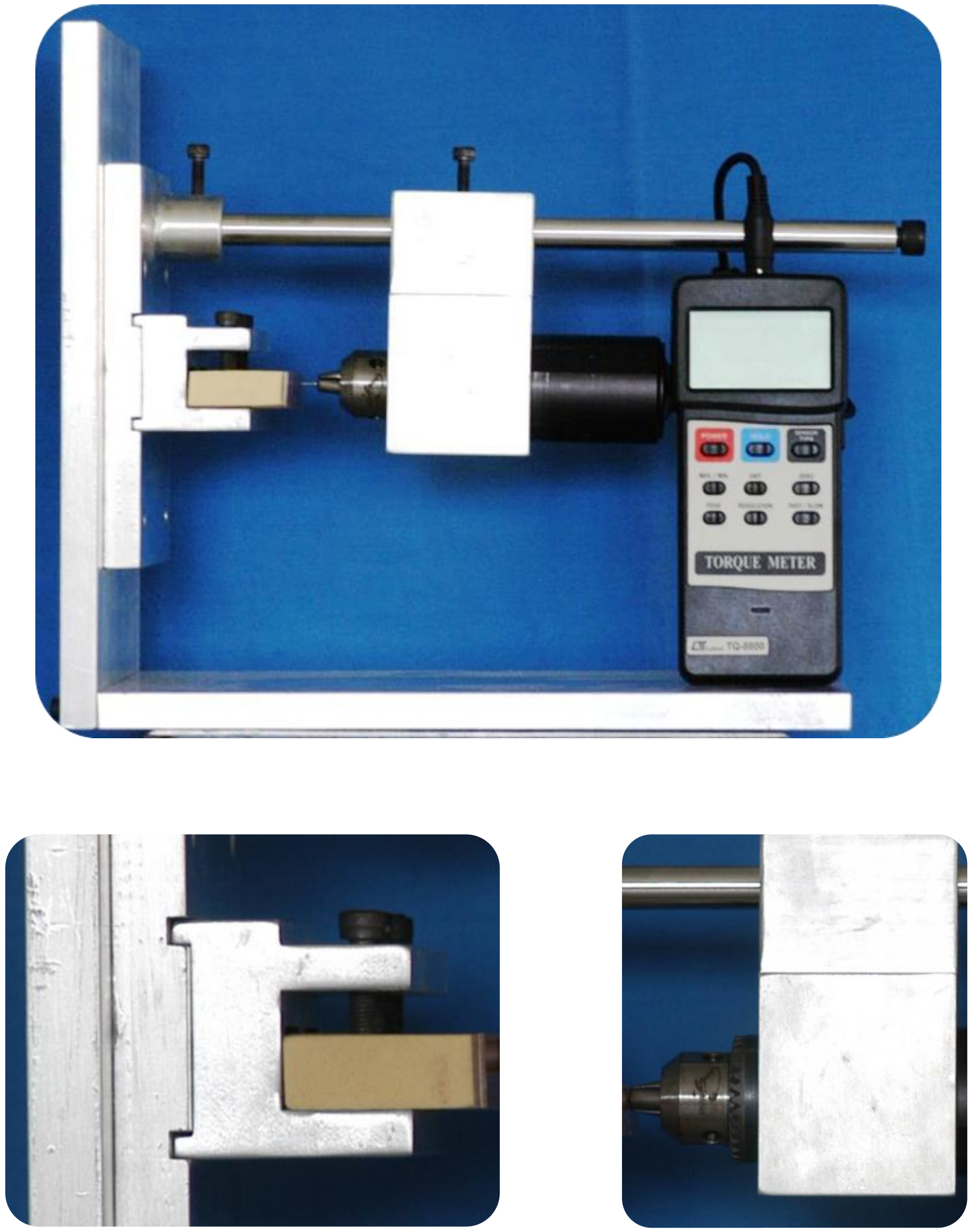


Fig 3- Synthetic bone blocks cut into rectangular blocks of 30 X 40 X 120mm each with different cortical bone thickness (1mm, 2mm, 3mm) and bone density of 30pcf.

Fig 4- Digital torque driver with torque measuring meter. (Lutron TQ8800; Taiwan)



A **B**

Fig 5- Aluminium custom-made apparatus. A) slider with a clamp

B) torquimeter driver guide;

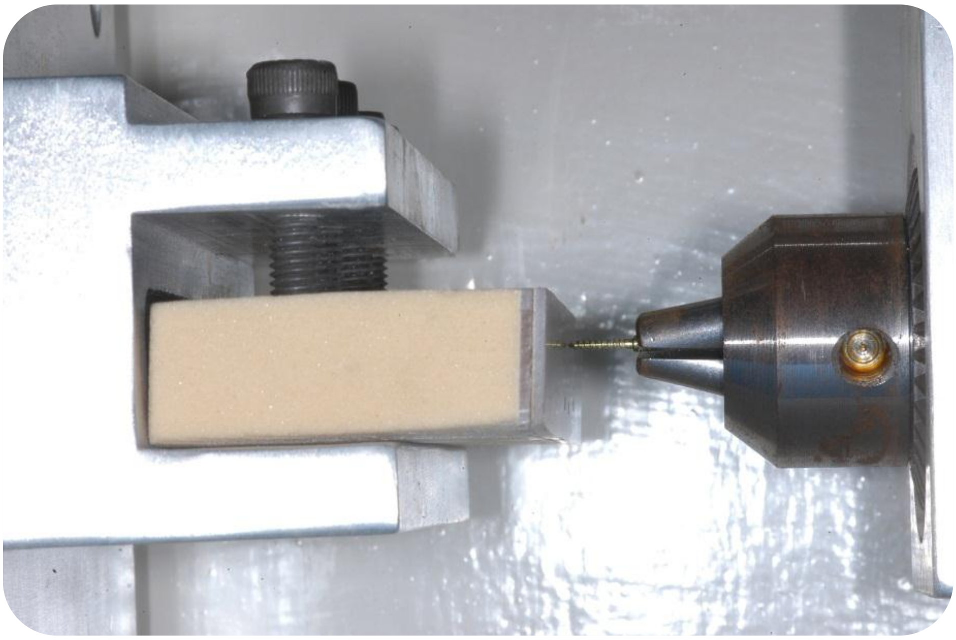


Fig 6 - MSI perpendicular to the artificial bone surface prior to its insertion at a pre-determined point.

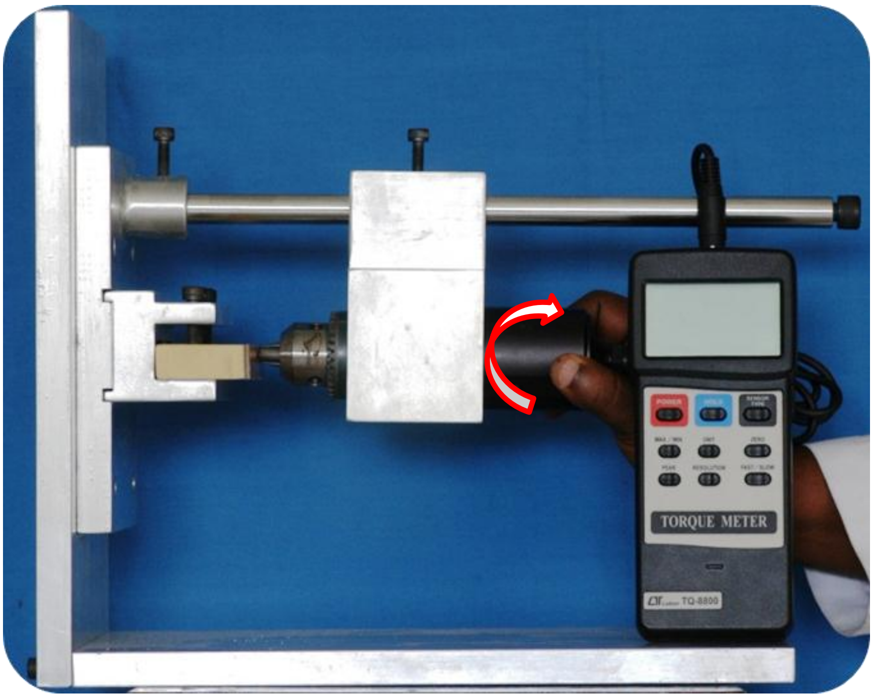


Fig 7- MSI's inserted into the bone blocks using finger pressure in a clockwise rotational axis.

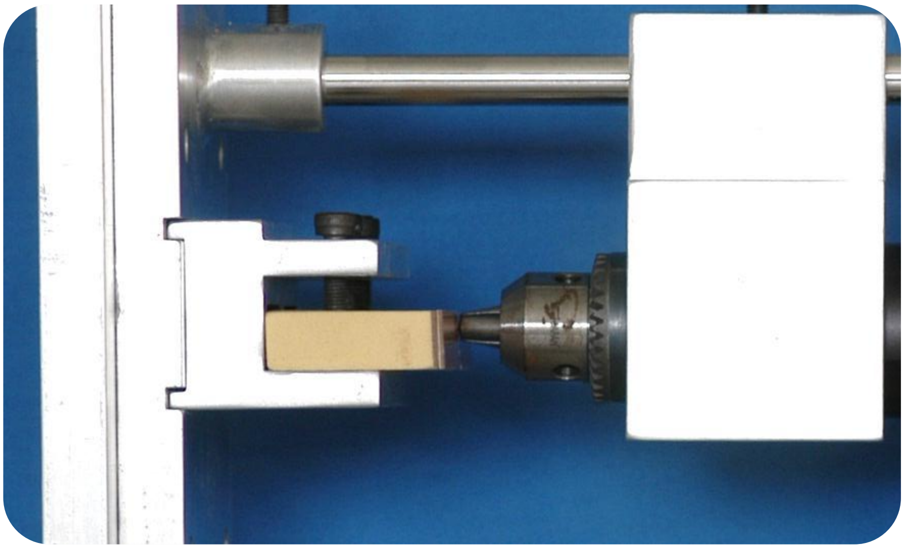


Fig 8- MSI's inserted until the head contacted and compressed the artificial bone surface to obtain true measurement of peak insertion torque values.

Fig 9- MSI's evaluated macroscopically for dimensional changes, distortion and fracture (control)

Figure 10: HITACHI, S3000N Scanning Electron Microscope (SEM) (Hitachi, Tokyo, Japan)

RESULTS

This study was done to evaluate the peak insertion torque and the dimensional changes of varying diameters of MSI inserted into varying cortical bone thickness. After evaluating the peak insertion torque of each varying diameter of MSI in each cortical bone thickness, all the MSI's were retrieved for evaluation for dimensional changes, distortion and fracture of MSI's macroscopically and under scanning electron microscope.

EVALUATION OF INSERTION TORQUE

Diameter of MSI:

The Peak insertion torque for varying diameters of MSI's (1.2mm,1.3mm,1.4mm and 1.5mm) were evaluated and descriptive statistics are given in **(Table 5) and (Fig 11).**

The mean peak insertion torque for 1.2mm diameter MSI was 7.027± 1.16Ncm, with minimum and maximum insertion torque values of 5.40Ncm and 8.80Ncm respectively.

The mean peak insertion torque for 1.3mm diameter MSI was 8.06±1.14Ncm, with minimum and maximum insertion torque values of 6.60Ncm and 9.80Ncm respectively.

The mean peak insertion torque for 1.4mm diameter MSI was 10.02± 1.29Ncm, with minimum and maximum insertion values of 8.30Ncm and 11.80Ncm respectively.

The mean peak insertion torque for 1.5mm diameter MSI was 11.37 ± 1.48 Ncm, with minimum and maximum insertion torque values of 9.50Ncm and 13.40Ncm respectively.

All the Mean peak insertion torque values were statistically very significant with a P value of (0.001). The results showed with increase in the diameter of MSI, there was a proportionate increase in the peak insertion torque values irrespective of the different cortical bone thickness (1mm, 2mm and 3mm).

Miniscrew implant of different diameters were compared, it was found that their peak torsional strength values increased as the diameters of the MSI increased.

Different cortical bone thickness

The Peak insertion torque for MSI's inserted into different cortical bone thickness (1mm,2mm,3mm) were evaluated and descriptive statistics are given in the **(Table 6)and(Fig 12).**

The overall mean peak insertion torque when varying diameters of MSI's were inserted into 1mm of cortical bone thickness was 7.666 ± 1.52Ncm, with a minimum and maximum torque values of 5.40Ncm and 9.70Ncm respectively.

The overall mean peak insertion torque when varying diameters of MSI's were inserted into 2mm of cortical bone thickness was 9.062 ± 1.83Ncm with a minimum and maximum torque values of 6.80Ncm and 11.80Ncm respectively.

The overall mean peak insertion torque when varying diameters of MSI's were inserted into 3mm of cortical bone thickness was 10.641 ± 1.85N cm, with a minimum and maximum torque values of 6.80Ncm and 11.80Ncm respectively .

All the Mean insertion torque values recorded were statistically very significant at P value of (0.001). The results of peak insertion torque values for MSI's inserted into different cortical bone thickness showed, with increase in the cortical bone thickness, there was a proportionate increase in the peak insertion torque values.

The mean peak insertion torque recorded when all the seventy two MSI's of varying diameters were inserted into different cortical bone thickness was 9.123 ± 2.109Ncm, with minimum and maximum torque values of 5.40Ncm and 13.40Ncm respectively with a statistically very significant P value (0.001). **(Fig 13)**

<u>One way ANOVA presented with 95% C.I</u>

<u>Diameter of MSI :</u>

The peak insertion torque for varying diameters of MSI's were evaluated with One way ANOVA and were presented with 95% confidence interaval**. (Table7)**

As the diameter of the MSI increases from 1.2mm, 1.3mm, 1.4mm, 1.5mm the mean peak insertion torque value correspondingly increased from 7.027Ncm, 8.066Ncm, 10.027Ncm, 11.372Ncm respectively with a statistically very significant P value (0.001).

The results showed that the mean peak insertion torque values increased with an increase in the diameter of the MSI. Miniscrew implants with greater diameter had the highest mean torsional values, whereas those with smaller diameter had the lowest mean torsional values.

Different cortical bone thickness :

The Peak insertion torque for MSI's inserted into different cortical bone thickness were evaluated with One way ANOVA and were presented with 95% confidence interval. **(Table 8)**

As the cortical bone thickness increases from 1mm, 2mm, 3mm the mean peak insertion torque values increases from 7.066Ncm, 9.062Ncm, 10.641Ncm respectively with a statistically very significant P value of (0.001).

The results showed that the mean peak insertion torque values increases with an increase in the thickness of the cortical bone.

POST HOC TEST (BONFERRONI) presented with 95% C.I

Diameter of MSI :

Each diameter of MSI was subjected to multiple comparisons with their mean peak insertion torque values, and were evaluated with POST HOC TEST (BONFERRONI) which were presented with 95% confidence interval**.(Table9)**

When the mean peak insertion torque of 1.2mm diameter of MSI was compared to the mean peak insertion torque of 1.3mm,1.4mm and 1.5mm diameter of MSI it showed a Mean peak insertion torque differences of

1.03Ncm, 3.00Ncm, 4.34Ncm respectively with a statistically significant P value (0.001) .

When the mean peak insertion torque of 1.3mm diameter of MSI was compared to the mean peak insertion torque of 1.4mm and 1.5mm diameter of MSI it showed a Mean peak insertion torque differences of 1.96Ncm, and 3.30Ncm respectively with a statistically significant P value (0.001) .

When the mean peak insertion torque of 1.4mm diameter of MSI was compared to the mean peak insertion torque of 1.5mm diameter of MSI it showed a Mean peak insertion torque differences of 1.34Ncm with a statistically sigbificant P value (0.001).

The results showed that, with increase in varying diameters of MSI's, there was a statistically significant increase in mean peak insertion torque values.

Cortical bone thickness :

Each cortical bone thickness were subjected to multiple comparisons with their mean peak insertion torque values, and were evaluated with POST HOC TEST (BONFERRONI) which were presented with 95% confidence interval**. (Table10)**

When the mean peak insertion torque of MSI's inserted into 1mm cortical bone thickness were compared to the mean peak insertion torqueof MSI's inserted into 2mm and 3mm of cortical bone thickness, it showed a Mean peak insertion torque differences of 1.39Ncm and 2.97Ncm respectively with a statistically significant P value(0.001).

When the mean peak insertion torque of MSI's inserted into 2mm cortical bone thickness were compared to the mean peak insertion torque of MSI's inserted into 3mm cortical bone thickness, it showed a Mean peak insertion torque difference of 1.57Ncm with a statistically significant P value (0.001).

The results showed that, with increase in cortical bone thickness, there was a statistically significant increase in mean peak insertion torque values.

EVALUATION OF DIMENSIONAL CHANGES

All the MSI's were evaluated for dimensional changes, distortion, and fracture. All the retreived MSI's were evaluated both macroscopically and under scanning electon microscope. One MSI in each diameter, which were not inserted into different cortical bone thickness were scanned using scanning electron microscope and they served as control for comparison. **(Fig 14)**

Macroscopic evaluation

Out of the 72 MSI's tested, 5 MSI's showed visible distortion or bending **(Fig15)**, and 2 MSI's showed fracture **(Fig 16)**.

Scanning electron microscope evaluation

The surface dimensional changes for all the retreived MSI's were further evaluated under SEM at various magnifications at 10x and 50x. The photomicrographs obtained were evaluated for dimensional changes, distortion and fracture sites. All the retreived MSI's were evaluated specifically at the tip of the MSI, threads and shaft core and were compared with unused MSI in each diameter which served as the control.

The **1.2mm diameter MSI inserted into 1mm cortical bone thickness** showed surface dimensional changes, such as fatigue striations and less sharp tip. Smoothening of the threads were observed at 10x and 50x magnifications. **(Fig 17)**

The **1.2mm diameter MSI inserted into 2mm cortical bone thickness** showed surface dimensional changes, such as fatigue striations at its tip, threads and the shaft core. Blunting of MSI tips were observed at 10x and 50x magnifications. **(Fig 18)**

The **1.2mm diameter MSI inserted into 3mm cortical bone thickness** showed pronounced surface dimensional changes and striations at the tip, thread and shaft core at 10x magnification. Fatigue fracture and ductile fracture at the thread shaft interface were observed. There were no defects in form of pores or cracks at the fractured interface at 50x magnification. **(Fig 19)**

The **1.3mm diameter MSI inserted into 1mm cortical bone thickness** showed surface dimensional changes, such as fatigue striations and less sharp tip. Smoothening of the threads were observed at 10x and 50x magnifications. **(Fig 20)**

The **1.3mm diameter MSI inserted into 2mm cortical bone thickness** showed surface dimensional changes, such as fatigue striations at its tip, threads and the shaft core. Blunting of MSI tips were observed at 10x and 50x magnifications. **(Fig 21)**

The **1.3mm diameter MSI inserted into 3mm cortical bone thickness** showed pronounced surface dimensional changes and striations at the tip, thread and shaft core at 10x magnification. Fatigue fracture and ductile fracture at the thread shaft interface were observed. There were no defects in form of pores or cracks at the fractured interface at 50x magnification. **(Fig 22)**

The **1.4mm diameter MSI inserted into 1mm cortical bone thickness** showed resistance to surface dimensional changes with minimal fatigue straitions seen at its tip and threads at 10x and 50x magnifications. **(Fig 23)**

The **1.4mm diameter MSI inserted into 2mm cortical bone thickness** showed pronounced surface dimensional changes such as fatigue striations at its tip, threads and shaft core, and less sharp tip at 10x and 50x magnifications. **(Fig 24)**

The **1.4mm diameter MSI inserted into 3mm cortical bone thickness** showed pronounced surface dimensional changes such as fatigue straitions at its tip, threads and shaft core at 10x magnification. Blunting of MSI tips and threads were observed at 50x magnification. **(Fig 25)**

The **1.5mm diameter MSI inserted into 1mm cortical bone thickness** showed resistance to surface dimensional changes with minimal fatigue straitions seen at its tip and threads at 10x and 50x magnifications. **(Fig 26)**

The **1.5mm diameter MSI inserted into 2mm cortical bone thickness** showed pronounced surface dimensional changes such as fatigue striations at its tip, threads and shaft core, and less sharp tip at 10x and 50x magnifications. **(Fig 27)**

The **1.5mm diameter MSI inserted into 3mm cortical bone thickness** showed pronounced surface dimensional changes such as fatigue straitions at its tip, threads and shaft core at 10x magnification. Blunting of MSI tips and threads were observed at 50x magnification. **(Fig 28)**

<u>Distortion :</u>

Out of the 72 MSI's tested, 5 MSI's underwent distortion while insertion. The MSI's which underwent distortion were 1.2mm diameter when inserted into 2mm cortical bone thickness and 3mm cortical bone thickness, and 1.3mm diameter MSI when inserted into 3mm cortical bone thickness**.** The occurrence of MSI distortion or bending was 6.94% in our study.

The peak insertion torque recorded for distortion of 1.2mm diameter MSI's on insertion into 2mm cortical bone thickness was 10Ncm, and when inserted into 3mm cortical bone thickness were 10.4Ncm, 11Ncm. For 1.3mm diameter MSI inserted into 3mm cortical bone thickness , the peak insertion torque values recorded for distortion were 11.9Ncm, 11 .8Ncm.

Fracture :

The two MSI's which fractured were 1.2mm diameter MSI when inserted into 3mm cortical bone thickness and 1.3mm diameter MSI when inserted into 3mm cortical bone thickness**.** The occurrence of fracture was 2.6% in our study.

The SEM images of the fractured surfaces (cross section) **(fig 19,22),** revealed fatigue striations which are an indication of the fatigue torsional failure due to increased torsional stresses. Both the fracture locations of the MSI's were closer to the shoulder of the MSI and was between the interface of the thread and the shaft which signifies the build up of high torsional stresses at these areas on insertion of small diameter (1.2mm and 1.3mm) MSI's into dense cortical bone thickness (3mm). There were no defects in form of pores or cracks observed at the fractured interfaces.

The peak insertion torque values recorded for fracture of 1.2mm and 1.3mm diameter MSI's during insertion into 3mm cortical bone thickness were 12.50Ncm and 13.40Ncm.

TABLE- 4 Mean peak insertion torque values of varying diameters of MSI's.

DIAMETER	N	MEAN (Ncm)	STANDARD DEVIATION	MINIMUM (Ncm)	MAXIMUM (Ncm)
1.2mm	18	7.027	1.160	5.40	8.80
1.3mm	18	8.066	1.140	6.60	9.80
1.4mm	18	10.027	1.297	8.30	11.80
1.5mm	18	11.372	1.485	9.50	13.40
TOTAL	**72**	**9.123**	**2.109**	**5.40**	**13.40**

TABLE-5 Mean peak insertion torque values of different cortical bone thickness

CORTICAL BONE THICKNESS	N	MEAN TORQUE (Ncm)	STANDARD DEVIATION	MINIMUM TORQUE (Ncm)	MAXIMUM TORQUE (Ncm)
1mm	24	7.667	1.526	5.40	9.70
2mm	24	9.0625	1.831	6.80	11.80
3mm	24	10.6417	1.85	8.10	13.40
TOTAL	**72**	**9.123**	**2.109**	**5.40**	**13.40**

TABLE-6 ONE WAY ANOVA

DIAMETER	N	MEAN TORQUE (Ncm)	STANDARD DEVIATION	95% Confidence interval for Mean		P VALUE (0.05)
				LOWER BOUND	UPPER BOUND	
1.2mm	18	7.027	1.160	6.450	7.604	0.05
1.3mm	18	8.066	1.140	7.499	8.633	0.05
1.4mm	18	10.027	1.297	9.382	10.673	0.05
1.5mm	18	11.372	1.485	10.673	12.111	0.05

P value ≤ 0.05 indicating statistical significance.

TABLE- 7 ONE WAY ANOVA

CORTICAL BONE THICKNESS	N	MEAN TORQUE (Ncm)	STANDARD DEVIATON	95% Confidence interval for MEAN		P VALUE (0.05)
				LOWER BOUND	UPPER BOUND	
1mm	24	7.667	1.526	7.022	8.311	0.05
2mm	24	9.0625	1.831	8.289	9.835	0.05
3mm	24	10.6417	1.85	9.859	11.424	0.05

P value ≤ 0.05 indicating statistical significance.

TABLE-8 Comparison of mean peak insertion torque values between the varying diameters of MSI's.

DIAMETER (I)	DIAMETER (J)	N	MEAN ±SD TORQUE (Ncm)	COMPARISON	MEAN DIFFERENCE (Ncm)	P VALUE (0.05)
1.2mm	1.3mm	18	7.027	1.2mm - 1.3mm	-1.038	.104
	1.4mm			1.2mm – 1.4mm	-3.000	.000
	1.5mm			1.2mm – 1.5mm	-4.344	.000
1.3mm	1.2mm	18	8.066	1.3mm – 1.2mm	1.038	.104
	1.4mm			1.3mm – 1.4mm	-1.961	.000
	1.5mm			1.3mm – 1.5mm	-3.305	.000
1.4mm	1.2mm	18	10.027	1.4mm – 1.2mm	3.000	.000
	1.3mm			1.4mm – 1.3mm	1.961	.000
	1.5mm			1.4mm – 1.5mm	-1.344	.014
1.5mm	1.2mm	18	11.372	1.5mm – 1.2mm	4.344	.000
	1.3mm			1.5mm – 1.3mm	3.305	.000
	1.4mm			1.5mm – 1.4mm	1.344	.014

P value ≤ 0.05 indicating statistical significance.

TABLE-9 Comparison of mean peak insertion torque values between the different cortical bone thickness.

DIAMETER (mm)		N	MEAN ±SD TORQUE (Ncm)	COMPARISON	MEAN DIFFERENCE (Ncm)	P VALUE (0.05)
1mm	2mm			1mm – 2mm	-1.395	.021
	3mm	24	7.667	1mm – 3mm	-2.975	.000
2mm	1mm			2mm – 1mm	1.395	.021
	3mm	24	9.0625	2mm – 3mm	-1.579	.008
3mm	1mm			3mm – 1mm	2.975	.000
	2mm	24	10.6417	3mm – 2mm	1.579	.008

P value ≤ 0.05 indicating statistical significance.

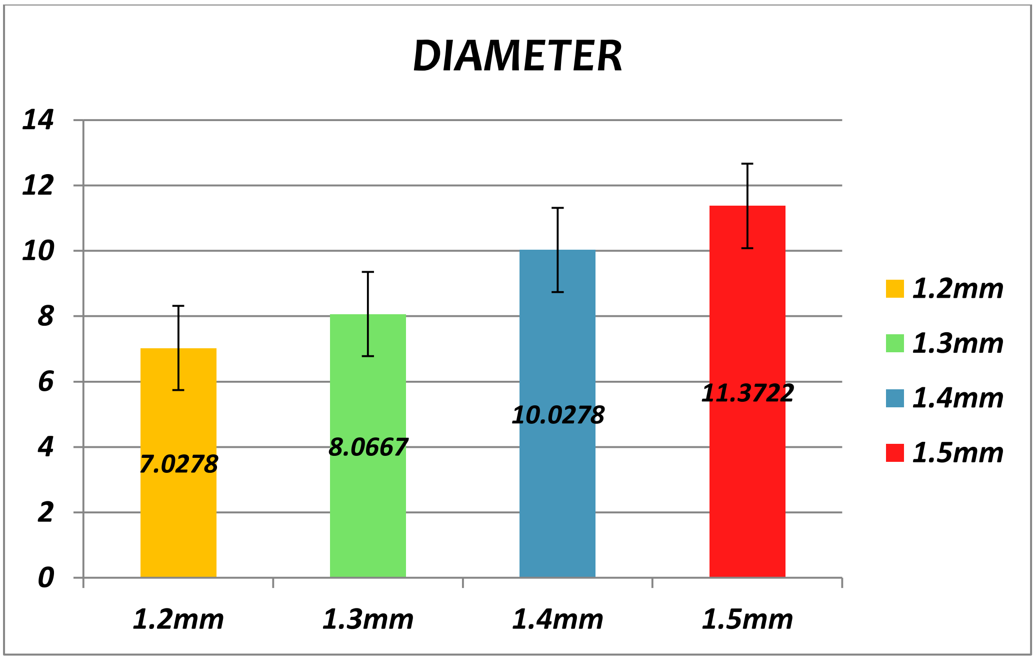


Figure 11: Mean peak insertion torque values for different diameters of MSI.

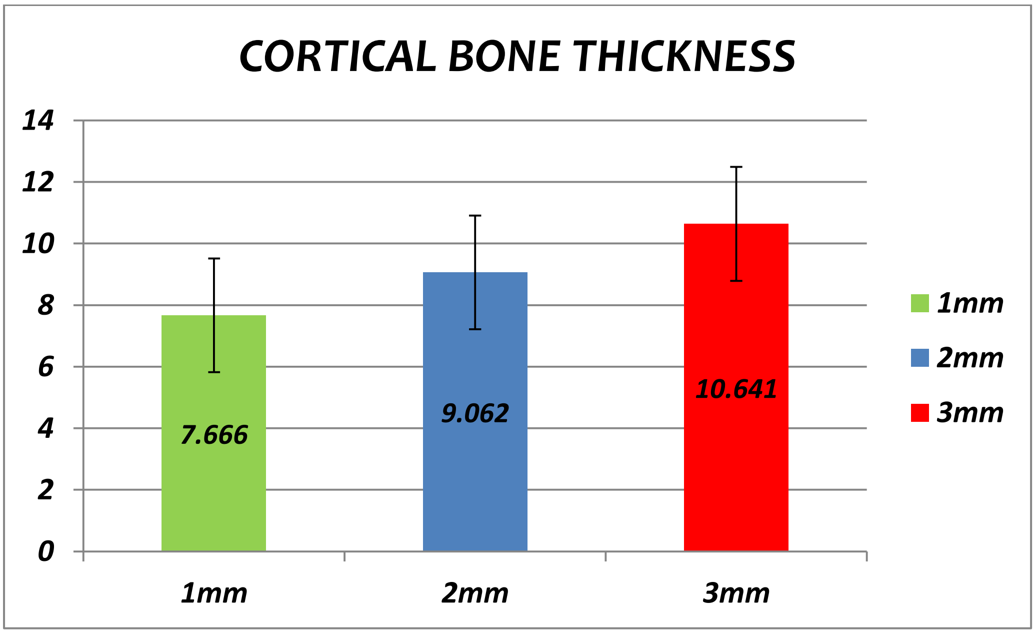
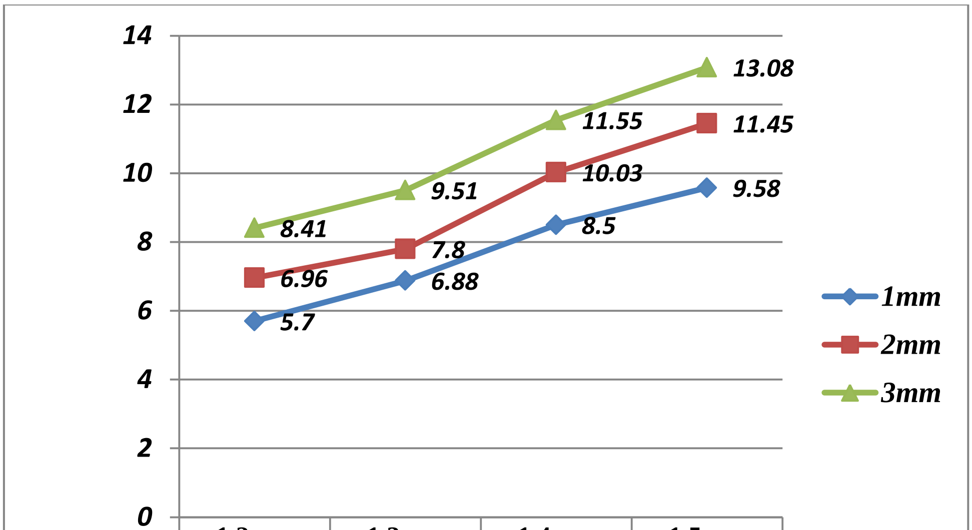


Figure 12: Mean peak insertion torque values for different cortical bone thickness.



	1.2mm	1.3mm	1.4mm	1.5mm
1mm	5.7	6.88	8.5	9.58
2mm	6.96	7.8	10.03	11.45
3mm	8.41	9.51	11.55	13.08

Fig – 13 Mean peak insertion torque values for varying diameters of MSI's inserted into different cortical bone thickness

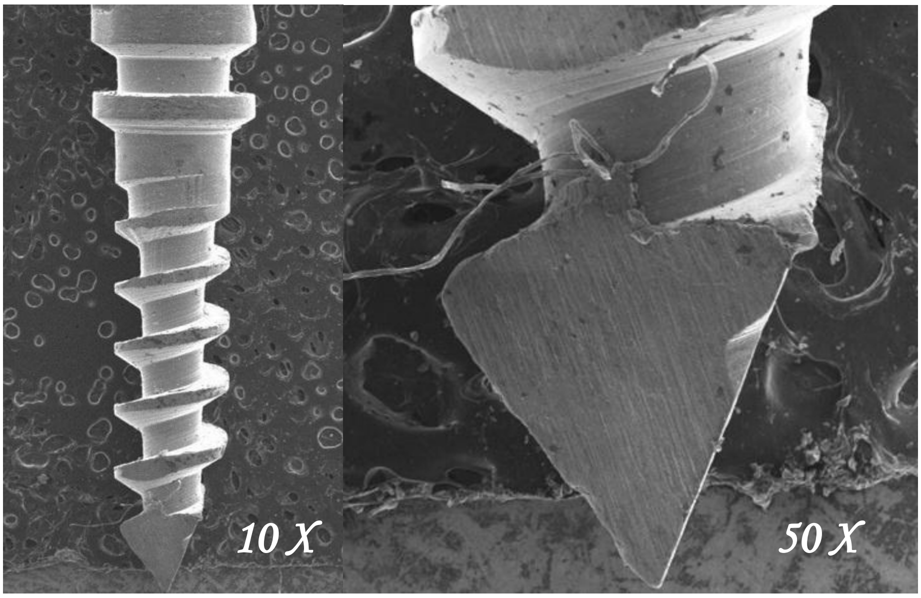


Fig 14- SEM image of as-received MSI (control) used for comparing with retrieved MSI's for dimensional changes at 10x and 50x.

Fig 15- Macroscopic evaluation of a distorted MSI.

Fig 16- Macroscopic evaluation of a fractured MSI.

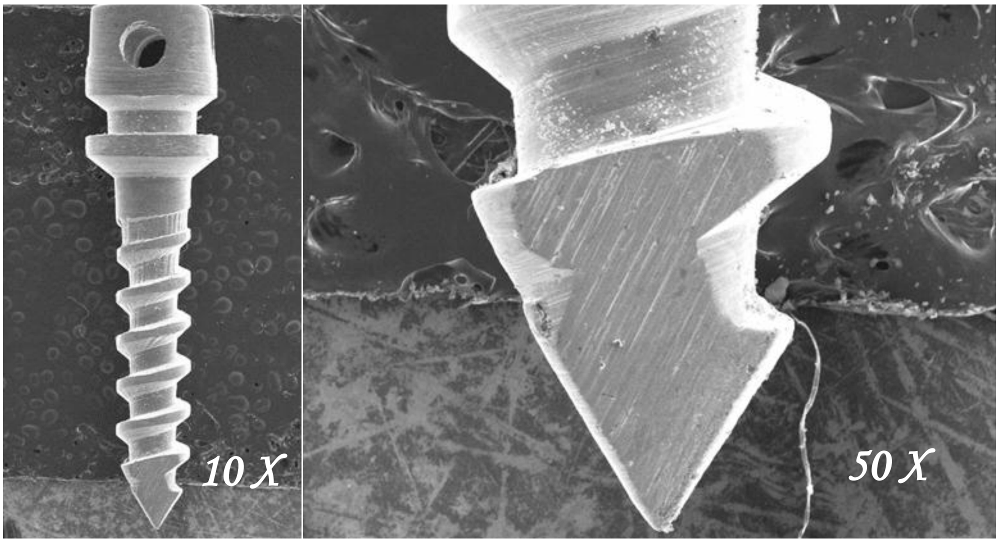


Fig 17 – SEM image of 1.2mm diameter MSI inserted into 1mm Cortical bone thickness at 10x and 50x.

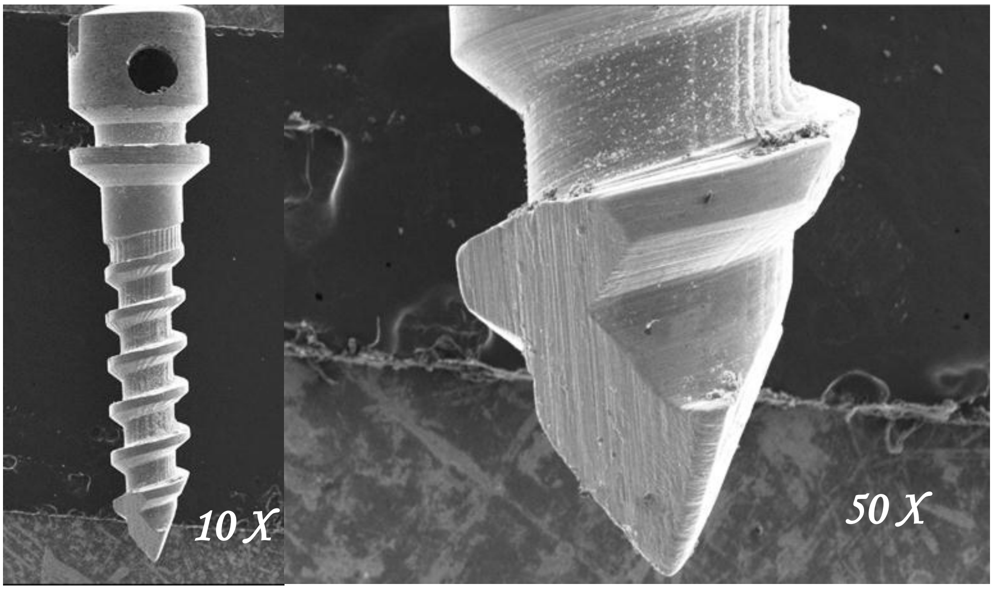


Fig 18 - SEM image of 1.2mm diameter MSI inserted into 2mm Cortical bone thickness at 10x and 50x.

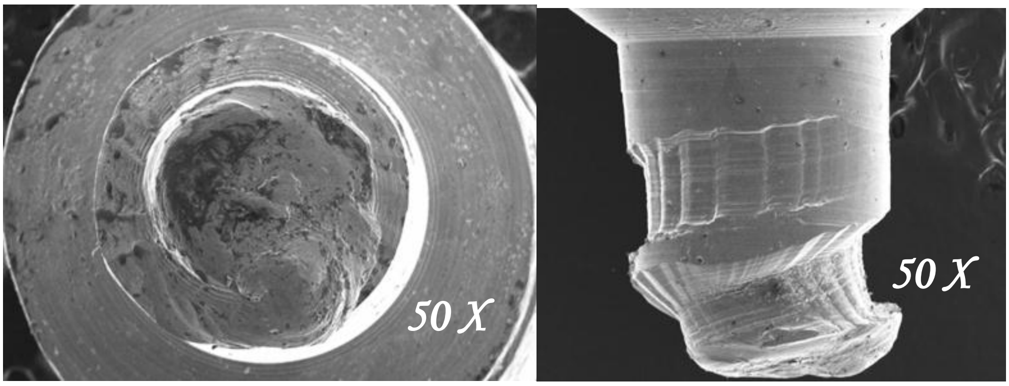


Fig 19-Cross-section SEM image of 1.2mm diameter MSI inserted into 3mm Cortical bone thickness at 50x showing fracture at thread core interface.

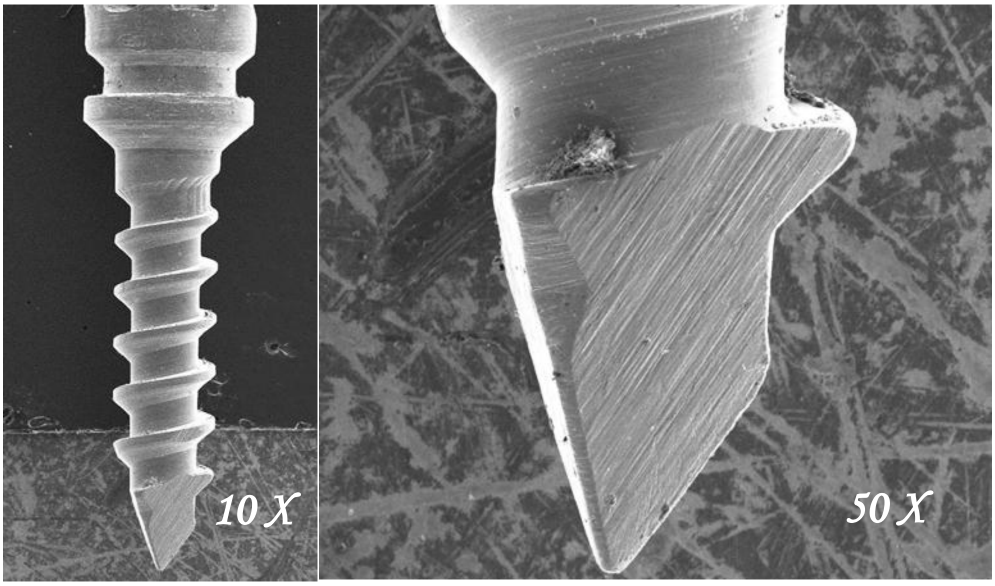


Fig 20 - SEM image of 1.3mm diameter MSI inserted into 1mm Cortical bone thickness at 10x and 50x.

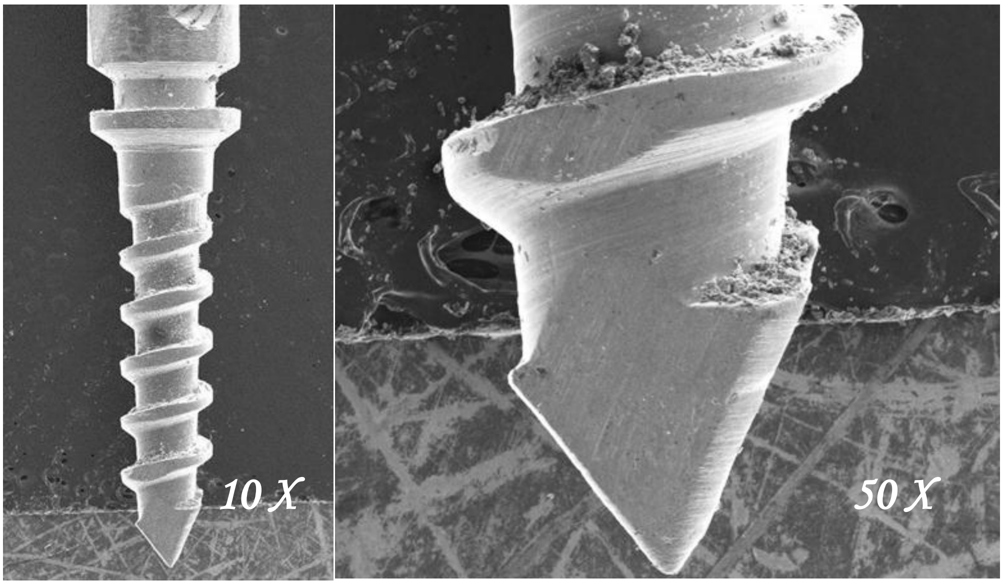


Fig 21- SEM image of 1.3mm diameter MSI inserted into 2mm Cortical bone thickness at 10x and 50x.

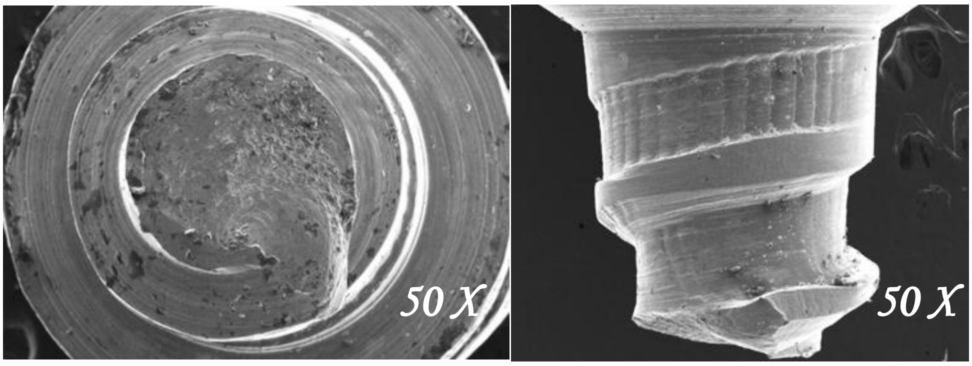


Fig 22 – Cross-section SEM image of 1.3mm diameter MSI inserted into 3mm Cortical bone thickness at 50x showing fracture at thread core interface.

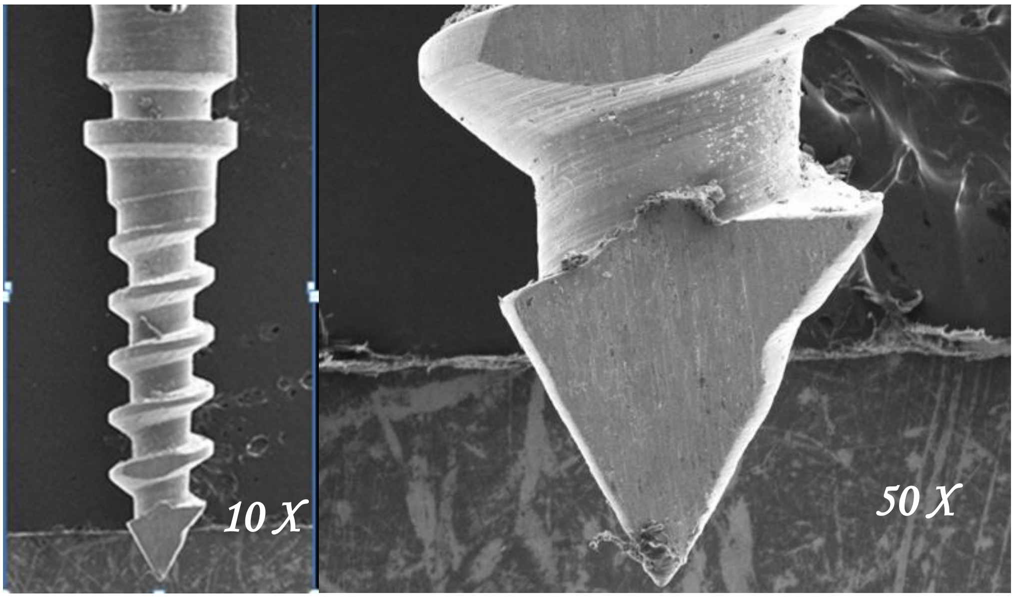


Fig 23 - SEM image of 1.4mm diameter MSI inserted into 1mm Cortical bone thickness at 10x and 50x.

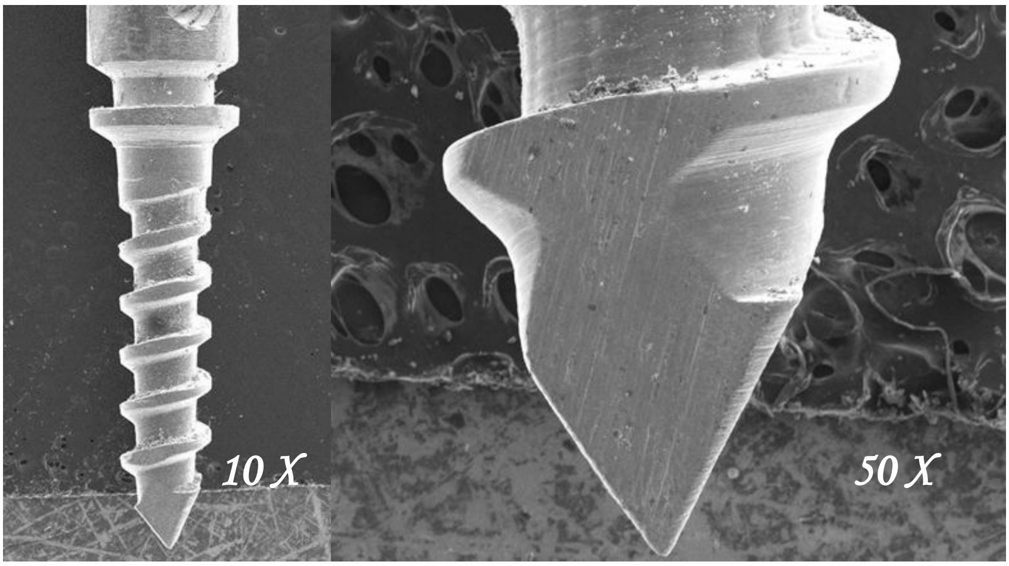


Fig 24 - SEM image of 1.4mm diameter MSI inserted into 2mm Cortical bone thickness at 10x and 50x.

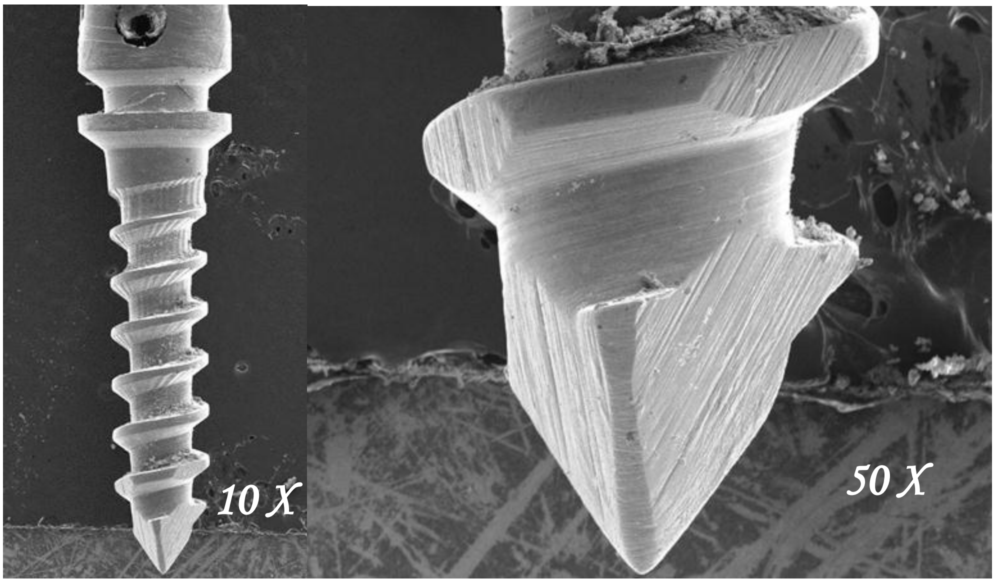


Fig 25- SEM image of 1.4mm diameter MSI inserted into 3mm Cortical bone thickness at 10x and 50x.

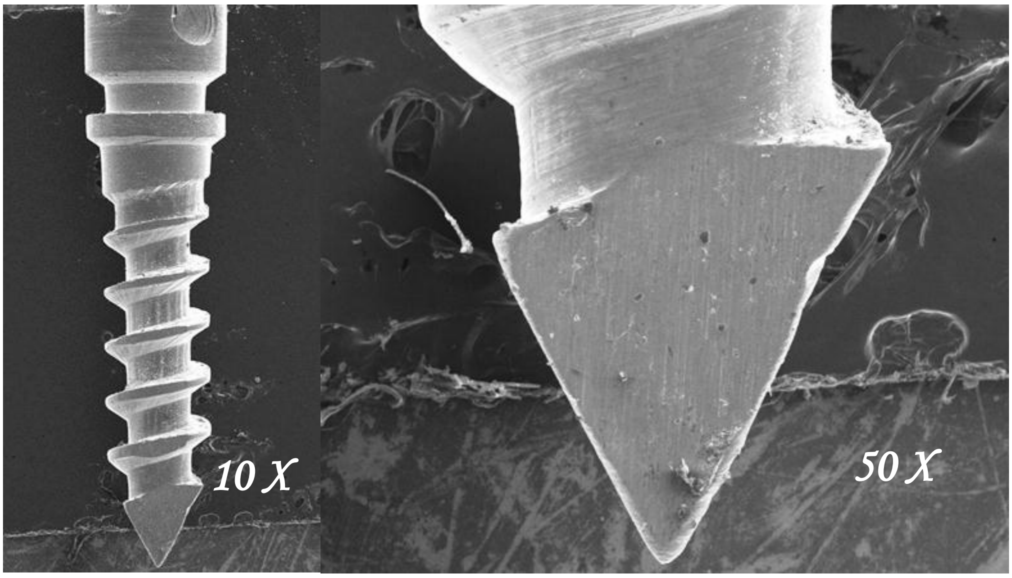


Fig 26 - SEM image of 1.5mm diameter MSI inserted into 1mm Cortical bone thickness at 10x and 50x.

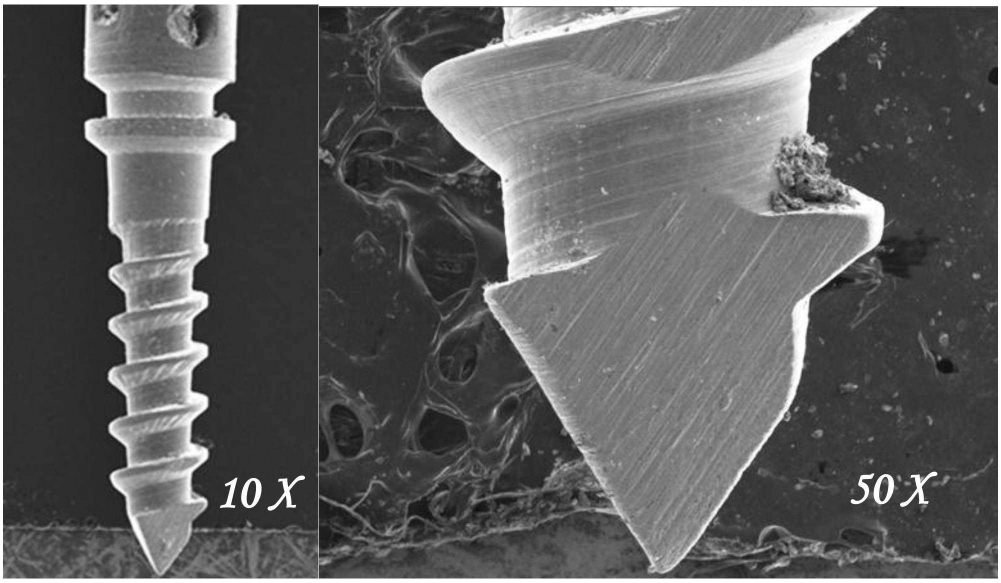


Fig 27 - SEM image of 1.5mm diameter MSI inserted into 2mm Cortical bone thickness at 10x and 50x.

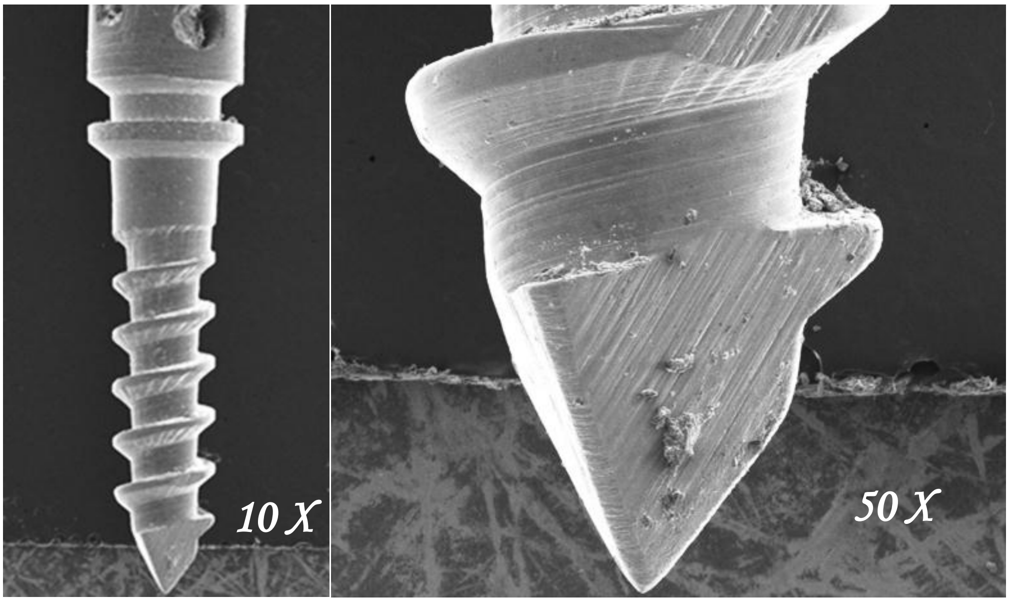


Fig 28 - SEM image of 1.5mm diameter MSI inserted into 3mm Cortical bone thickness at 10x and 50x.

DISCUSSION

This experimental In-vitro study was done to evaluate the insertion torque of varying diameters of MSI's inserted into different cortical bone thickness and, to specifically assess whether different cortical bone thickness has an effect on the dimensional changes of the MSI's using scanning electron microscope.

Both miniscrew implant and the host factors affect the initial stability of MSIs. The miniscrew implant factors are related to the screws design, including, but not limited to, their outer diameter and length **(Gray et al)** [34]. The host factors are related to the quantity (cortical thickness) and quality (cortical density) of the bone into which the screws are placed **(Park et al)** [76]**.**

Despite the great popularity achieved by MSI, there are few studies assessing their mechanical characteristics **(Song et al)** [86]. Several case studies have been published since the emergence of MSI, but their mechanical features are rarely assessed. It seems rational to assess the mechanical characteristics of these orthodontic products because of their reduced diameter, which may lead to a decreased mechanical resistance and consequently reduced maximum torque for permanent deformation and fracture **(Elias et al)** [24]**.**

While the importance of varying diameters of MSI and cortical bone thickness have been evaluated , how they interact to influence and enhance the primary stability of the MSI's still remains unclear. Moreover, few studies have evaluated both the insertion torque and fracture torque of the MSI's

(Maria Nova et al) [59]. But there are no studies, which have evaluated the dimensional changes of varying diameters of MSI's inserted into different cortical bone thickness. It is important to evaluate both , the insertion torque as it provides information pertaining to the primary stability, and dimensional changes of MSI's as it provides information pertaining to the mechanical limitations of the MSI **(Song et al)** [86]**.** Some of the factors tested in this study were MSI related factor (diameter) and bone related factor (cortical bone thickness). Therefore, the primary aim of this study was to evaluate the peak insertion torque of varying diameters of MSI's inserted into different cortical bone thickness. The secondary aim was to evaluate whether the thickness of different cortical bone thickness has an effect on the dimensional changes of MSI's.

<u>Diameter of MSI:</u>

Safety is a major consideration when MSI's are placed in the bone and can be achieved by ensuring that the proposed MSI site has adequate inter-radicular space to accommodate the diameter of MSI, thereby avoiding any root damage.

Miyawaki et al[65] showed that diameter of the MSI is significantly associated with its stability. They also found MSI with 1mm diameter is at risk of more failure and 0 % success rate. However, the 1.2 mm, 1.3 mm and 1.5 mm diameter MSI had higher success rates than the 1.6mm MSI.

Though thinner MSI's are easier to place in most inter-dental locations, the drawback of thinner MSI's is the greater potential for screw fracture. **(Miyawaki et al)** [65]

To determine the ideal diameter of a MSI, a few studies assessed the inter-radicular spaces. **Liou et al** [57] recommended 2 mm of safety clearance between MSI and the dental root; thus, a 1.5mm diameter MSI would require 5.5mm of inter-radicular space width to ensure root integrity, making MSI placement impossible in most sites.

Park et al [75] agrees with the above studies and reported that the diameter of the MSI is restricted by the available inter-radicular space and the recommended diameter of MSIs to be placed in inter-radicular spaces is 1.2 to 1.6 mm and because of great anatomic variations, it is important to evaluate the anatomy of the desired location for implant placement and consider different diameters of MSIs for each patient.

Since, the most frequent insertion site for MSI is between the roots of the adjacent teeth, the inter-radicular distance determines the minimum and maximum diameter of the MSI. The position of the teeth and their angulations both labio-lingually and mesio-distally determine the area of bone available between their roots where an MSI might be positioned. For safe placement and primary stability of an MSI, its length is rather secondary, the diameter is much more important.

Poggio et al[75, 76] after studying the safe zone for MSI, also concluded that the diameter of MSI should not exceed 1.5mm. **Deguchi et al** [23], also agree in their 3D CT study that MSIs with diameters of 1.3 to 1.5mm are recommended for skeletal anchorage in inter-radicular areas. Small increase in the outer diameter of MSI, greater than 1.5mm diameter, increases the chances of potential root contact.

Hence, in accordance with the above mentioned studies, the MSI's tested in our study were selected according to the anatomic variations in various locations in the maxilla and the mandible. Since most of the clinical application of the MSI's are for the anchorage purposes, and due to the variations in the anatomy of buccal and the lingual inter-radicular spaces, the MSI's of varying diameters selected for this study were 1.2mm, 1.3mm, 1.4mm, and 1.5mm, which are in accordance with the above mentioned studies.

Length of MSI:

According to **Park et al** [78], the mean alveolar process widths ranged in general from 4 to 6 mm, this suggests the ideal length of the MSI. But longer MSI are chosen in the maxilla than mandible to achieve more mechanical interlocking to compensate for the decreased bone density. Since maxilla has more of cancellous bone than cortical bone, it has been recommended to use a longer MSI in the maxilla to improve the mechanical retention. But since the alveolar process widths have been reported to be between 4-6mm depth, using a longer MSI's more than 6mm depth might lead to MSI's being in close proximity to the vital structures, which is a safety concern. So taking safety and stability into consideration, in our study we have selected MSI's of 6mm length.

Lee et al [53] in their study reported that in terms of bucco-lingual thickness the only site that meets the requirement for MSI length, was between the first and second molars in the maxilla, showing as much as 5mm of mean safety depth. Since the depth of bone penetration might vary from 5mm to

7mm for most mono-cortical MSI's, the maxillary buccal intermolar region can be adequate for MSI of 5 to 7mm in length.

Deguchi et al [23] also agree in their 3D CT study that MSIs with lengths of 6 to 8mm are recommended for skeletal anchorage in inter-radicular areas.

Park et al [75] in their study also showed simulation of various lengths of MSIs (6mm, 8mm and 10mm) and placement angulations (0^0 and 15^0)and reported that even a slight error in the placement angulation can damage the roots, especially with longer implants. Hence, they suggested that for the reasons of both stability and safety, it might not be advisable to use a MSI longer than 6 to 7 mm.

Finite element studies by **Lee et al** [52] showed that the stress distribution inside the cortical bone have reported that the length of a MSI does not influence the maximum stress and stress distribution.

In our study the length of the MSI was kept as a constant variable. It is in accordance with the studies by **Park et al** [75]**, Lee et al** [52]**, Deguchi et al** [23] who showed that the recommended length for adequate primary stability and success were between 5mm and 7mm. Hence, 6mm length MSI's were selected in this study.

Further, finite element studies by **Lim et al and Baek et al** [56] have showed that the diameter rather than the length plays a greater role in their stability, as demonstrated in studies about stress distribution in reference to the length and diameter of the miniscrew and cortical bone thickness. Thus importance was given to the diameter of the MSI's rather than its length in our study.

Bone Density:

The host factors are related to quality and quantity of the bone. Both bone quality and quantity appear to be critical for successful placement of a MSI **(Choi et al)** [16]. Bone quality (density) surrounding the MSI has an impact on implant stability **(Choi et al, Park et al)** [16, 75].

Synthetic bone has been shown to be a good substitute for real bone **(Kim et al)** [49]. Synthetic bone, which is commonly used when evaluating MSI, makes it possible to control the variability of bone properties seen in the human cadaver and animal bones **(Lim et al, Song et al)** [55, 86]. The density of the artificial bone selected for this study was 30pcf (pounds per cubic foot). **Lim et al** [56] **and Motoyoshi et al** [67] in their study to evaluate the insertion torque have used bone density of 30-40pcf, which were similar to the bone density in various anatomic regions in the maxilla and the mandible.

Therefore in accordance with the above mentioned study, we have selected bone density of 30pcf in our study. The bone density variable in our study was kept as constant in-order to evaluate the effects of the bone quantity (cortical bone thickness).

Cortical Bone Thickness:

Cortical bone thickness is one of the most significant factors determining primary stability and consequently playing an important role in the success or failure of the MSI's. **Ansell et al** [1] reported stability of the

MSI's depends on the bone-to-screw contact, better bone quantity should result in better primary stability. Areas with thick cortex are considered to be better for miniscrew placement. **(Miyawaki et al, Huja et al)** [65, 40]**.**

Ono et al [73] reported that the average thickness of the maxillary cortical bone is approximately 1.2mm. **Kanazawa et al and Kasai et al** [45] measured the mandibular cortical bone and found that the thickness was between 2.0mm-2.2mm..

Park et al [75] **and Cho et al** [16] reported that the average buccal cortical bone thickness was 1.17 to 1.31mm and the average buccal mandibular cortical bone thickness ws 1.26 to 2.91mm and the average cortical bone thickness in the maxillary palatal alveolar process was 1.15 to 1.25mm and the retromolar pad area showed abundant cortical bone thickness of 1.96 to 2.06mm.

Since there are variations in the cortical bone thickness of the human maxilla and the mandible, which widely ranges from 1.17 to 2.91mm, synthetic bones were selected in this study with different cortical bone thickness of 1mm, 2mm, and 3mm. Hence, 1mm cortical bone served as a model for the thin human maxillary cortical bone, 3mm cortical bone thickness served as the model for the thicker human mandibular cortical bone. 2mm cortical bone thickness served as the model for variations between the thinnest and the thickest regions in the human maxillary and the mandibular cortical bone. Synthetic bones were chosen to control the variability of bone properties found in human cadaver and in the animal bones. **(Lim et al, Song et al)** [56, 86]

Sawbones with homogeneous cortical bone thickness and density in each block was used which is an equivalent for jaw bone **(Sawbones; Pacific Research Laboratories Inc., Washington, USA)**.

EVALUATION OF INSERTION TORQUE

It is generally thought that adequate placement torque is one of the principal factors affecting the primary stability when tightening the miniscrew implant into the bone.

Motoyoshi et al [67] found that the recommended placement torque was between 5Ncm – 10Ncm for successful implantation with the self-tapping MSI's in both the maxilla and the mandible. They further recommended that, regardless of the self-drilling or the self-tapping MSI's, the adequate placement torque range of the MSI's should be between 5Ncm – 10Ncm, and a placement technique that used a torque within that range should be selected.

Various techniques have been used to test the primary stability of MSI's. It is highly desirable to have a quantitative method for establishing primary implant stability at the time of placement. But insertion torque is the most commonly used method for testing the primary stability of the MSI's.

In our study, various diameters of MSI's were selected and inserted into different cortical bone thickness using a custom-made apparatus, which consisted of torquimeter driver guide, which allowed perpendicular path of

MSI insertion. MSI's were inserted into the bone blocks with the help of a digital torque driver using finger pressure. The peak insertion torque of varying diameters of MSI's and different cortical bone thickness were measured.

Meredith et al [62] recommended, of all the methods used to test the primary stability of the MSI's, he found insertion torque and resonance frequency analysis as the most reliable examinations.

Therefore, in concurrence with the recommendations by Meredith et al, insertion torque of varying diameters of MSI's on insertion into different cortical bone thickness were measured.

<u>Diameter of MSI:</u>

The results of our study showed that, when the diameter of the MSI's increases from 1.2mm, 1.3mm, 1.4mm and 1.5mm, the mean peak insertion torque values also correspondingly increased from 7.027Ncm, 8.066Ncm, 10.027Ncm and 11.372Ncm respectively **(Table 4)**. Each diameter of the MSI had a significant effect on the peak insertion torque. Hence, peak insertion torque values increases with an increase in diameter of the MSI, and this should be taken into consideration, while selecting a MSI for its primary stability.

The probable reason could be because, as the wider outer diameter of MSI increases, more bone is displaced during insertion, producing greater torsional stress at the bone-screw interface, leading to increase in the peak insertion torque values.

Study by Lim et al, evaluating the insertion torque of MSI's according to changes in diameter, length and shape found, as the diameter of the miniscrew implant increases, the insertion torque also increased, which were in concurrence with our findings.

A finite element analysis by **Lee et al** [52] showed that among the various miniscrew designs tested the change in diameter caused the greatest change in stress.

Elias et al [24] compared two types of MSI's from the same manufacturer with different diameters, he found that, the greater the diameter, greater was the MSI insertion torque, since it was proportional to the contact area between MSI and the bone. The results of this study were in concurrence with our findings.

A study by **Yan chen at al** [98] evaluated the insertion torque of different diameters of MSI's into different bone densities and found, as the diameter of the MSI's increases from 1.2mm,1.3mm,1.4mm,1.5mm and 1.6mm, the insertion torque also increases from 8.07Ncm, 9.97Ncm, 13.17Ncm, 13.29Ncm and 14.65Ncm respectively.

Chen et al [14] in his study using 1.2mm and 1.3mm self-drilling MSI's found that the peak insertion torque values were 5.6Ncm for maxilla and 8.7Ncm for the mandible. Results of Our study showed mean peak insertion torque recorded for 1.2mm and 1.3mm diameters were 7.02Ncm and 8.06Ncm respectively, which are in concurrence with the findings of Chen et al.

Results of our study showed as the diameter of MSI increased there was a proportional increase in insertion torque values which are in concurrence with the studies of Elias **et al** [24] **and Yan chen et al** [98]**.** However, study by Yan chen et al, showed several limitations, where bone densities alone were taken into consideration, omitting the cortical bone thickness which provided the primary stability. This might have influenced the slight variations in the insertion torque values.

Motoyoshi et al [67] showed that the mean insertion torque of MSI for the human subject was reported to range from 7.2Ncm – 13.5Ncm which was in accordance with our study where the mean peak insertion torque ranged from 7.027Ncm – 11.37Ncm for the MSI's of varying diameters (1.2mm, 1.3mm, 1.4mm and 1.5mm).

<u>Cortical Bone Thickness:</u>

Results of our study **(Table 5, 7, 9)**, showed, as the cortical bone thickness increased from 1mm, 2mm and 3mm, the mean peak insertion torque values correspondingly increased from 7.066Ncm, 9.062Ncm and 10.641Ncm respectively. This further reveals as the cortical bone thickness increases, there will be a proportionate increase in the mean peak insertion torque of the MSI. The results also suggests that, increase in cortical bone thickness has an significant effect on the mean peak insertion torque values with higher mean peak insertion torque values recorded for the thicker cortical bone.

Dalstra et al [21] showed that the maximum stress occurs at the cortical bone level when an implant is loaded. Using a finite element model, they showed that increasing cortical bone thickness drastically reduced the peak strain development in the peri-implant bone tissue. This inverse relationship between cortical bone thickness and peak strain development suggests that cortical bone thickness is a key determinant of initial stability.

Motoyoshi et al [67] recommend that the proposed MSI site should have a cortical bone thickness of atleast 1.0 mm for its primary stability. They stated that individuals with greater MSI success had significantly higher cortical bone thickness. Cortical bone thickness and insertion torque were significantly greater in the mandible than in the maxilla.

The results of our study was in concurrence with this study, as the thickness of the cortical bone increases, the insertion torque of the MSI's inserted into the thicker cortical bone also increases.

Salmoria et al [84] in his study reported that cortical thickness is one of the main factors influencing insertion torque and, consequently, primary stability and failure rate. More screw threads are able to engage into thicker cortical bone which, in turn, translates into greater insertion torque and greater primary stability.

Wilmes et al [95] reported a strong correlation between the cortical bone thickness and the insertion torque values, which was in accordance with our study, showing that each varying cortical bone thickness had a significant effect on the mean peak insertion torque values **(Table 7, 9)** and hence the results suggests a strong correlation between the cortical bone thickness and the mean peak insertion torque values.

Wilmes et al [95] reported that, amount of the torque during the placement of a MSI reflects the resistance it encounters when advancing into the bone. This resistance is proportional to the amount of bone compression during placement and therefore increases with greater cortical bone thickness.

Lim et al [55] reported that as the thickness of the cortical bone increases the maximum insertion torque increases. **Song et al** [86] in his study showed that when the cortical bone thickness increased from 1mm to 2mm, the insertion torque increased consistently.

The results of our study was in accordance with the study by **Song et al** [86]**, Whang et al** [92], and **Lim et al** [55]**,** which showed as the cortical bone thickness increases, the peak insertion torque values proportionately increased.

Hence, the peak insertion torque values increases with an increase in the cortical bone thickness, and should be taken into consideration when selecting a MSI for different anatomical sites in both the maxilla and mandible having different cortical bone thickness. The probable reason could be because, as the MSI is inserted into increasing cortical bone thickness, more bone is displaced during insertion, producing greater torsional stress at the bone-screw interface, leading to increase in the peak insertion torque values.

Heidemann et al [37] reported that pre-drilling is an effective method of decreasing the resisitance encountered during placement and thus reducing insertion torque. Therefore, in areas of increased cortical bone thickness, pre-drilling is recommended to remain in the ideal torque range.

EVALUATION OF DIMENSIONAL CHANGES

Although the small dimensions of miniscrew implant enable their insertion in various areas of the mouth, there is an increased likelihood of surface dimensional changes, deformation and fracture during insertion or removal into different cortical bone thickness.

According to the **(Draft International Standards 1996)** [42], retrieval analyses have gained greater interest in the dental materials area because of the critical information provided on the performance of the material in the environment in which it was intended to function. The development of international standards for the retrieval analysis of orthopedic materials strongly indicates the significance of this method in studying the performance of materials.

Eliades et al [25] reported that currently, there is little evidence on the profile of the implant surface during service, including structural alterations, changes in the mechanical properties, and various tissue-material interactions.

So this study also evaluated the effects of different cortical bone thickness on the dimensional changes of MSI's under a scanning electron microscope. Before the surface changes were observed, miniscrew implants were removed passively from the synthetic bone without any removal torque to preserve surface texture changes which occurred due to insertion torque. If MSIs were removed from the bone block with an active removal torque, additional surface damage would be artificially induced, thus masking the surface dimensional changes related to self-drilling insertion of varying MSI's diameters.

However, as mentioned in the previous study by **Eliades et al** [25], only morphological validation could be done with scanning electron microscope without quantitative and numeric analysis.

Diameter of MSI:

Results of this study evaluating the dimensional changes of varying diameters of MSI's on insertion into different cortical bone thickness showed significant dimensional changes of the smaller diameter MSI's when compared to the larger diameter MSI's.

The smaller diameter MSI's (1.2mm, 1.3mm) showed pronounced dimensional changes such as, blunting of the MSI tips and threads, fatigue striations at the tip, threads and shaft core. Fracture of the MSI's was observed at thread shaft interface. The smaller diameter MSI's showed significant decrease in the fracture resistance when inserted into thicker cortical bone.

The peak insertion torque values for distortion of 1.2mm diameter MSI recorded were 10Ncm, 10.4Ncm, 11Ncm, the peak insertion torque values for the distortion of 1.3mm diameter were 11.9Ncm and 11.8Ncm, and the peak insertion torque recorded during fracture of 1.2mm and 1.3mm diameters MSI's were 12.50Ncm and 13.40Ncm respectively.

One possible reason for the significant dimensional changes, distortion and the fracture experienced by the 1.2mm and the 1.3mm diameter MSI's could be because of peak insertion torque values recorded were much higher than the mean peak insertion torque values recorded for the 1.2mm diameter MSI’s which was 7.027Ncm, and the mean peak insertion torque values recorded for the 1.3mm diameter MSI’s which was 9.06Ncm, and were higher than the recommended insertion torque values by **Motoyoshi et al** [67] which was between 5Ncm – 10Ncm. So as the peak insertion torque values increases, there was an increase in inbuilt torsional stresses along the surface of the MSI’s from the tip to the shaft core, which leads to the failure of the MSI’s.

Kravitz et al and Kusnoto et al [50] reported that, the most common reason for the fracture is exposure to increased torsional stresses during placement or removal of the MSI’s.

Friberg et al [33] reported that a thick cortical bone with a high bone density may constitute a risk for the MSI fracture especially if a self-drilling MSI with a smaller diameter is used. He also reported that the implant placement resistance correlated positively with bone density, cortical thickness and MSI diameter.

Jolly and chung et al [44] reported that, smaller diameter of MSI may be advantageous to reduce the risk of damaging adjacent teeth. Though thinner MSI’s are easier to place in most inter-dental locations, the drawback of thinner MSI’s is the greater potential for screw fracture. **(Miyawaki et al)** [65]

Chen et al [14] reported that, as the peak insertion torque values of the MSI increases, there is a large amount of friction that develops between the MSI and the cortical bone, which leads to increased applied shearing force and which eventually leads to the failure of the MSI’s.

Maria Nova et al [59] reported that the smaller core diameter and the greater insertion torque can explain the smaller resistance to fracture of the MSI's.

Carono et al [9] compared the mechanical properties of two MSI's of same manufacturer of different diameters 1.3mm and 1.5mm. the results of their study demonstrated that the MSI's with lesser diameter 1.3mm presented considerably less resistance to bending and torsional strength than 1.5mm MSI's, suggesting that the diameter of the MSI's is directly correlated with the mechanical stability and that a reduction of the diameter by 0.2mm can have a significant effect on the mechanical properties.

The results of our study were in accordance with the above study by **Carono et al** [8], reporting that the self-drilling smaller diameter MSI's when inserted into dense cortical bone causes an increase in the torsional stresses and increased insertion torques, which leads to significant surface dimensional changes and eventually failure of the MSI's.

In our study, the MSI's fractured at the intra-osseous part at the thread and the shaft interface. This was in accordance with the study by **Whang et al** [92], who reported that all the MSI's tested fractured at the intra-osseous part rather than in the region of the head and neck, and it is hence unlikely that head and neck designs have an impact on the mechanical properties leading to different peak torque values.

Jolly and Chung et al [44] reported that, the risk of fracture is greater, for example without pilot hole drilling in the mandibular posterior region of high dense cortical bone. This in-vitro study documents a strong correlation between the maximum insertion torque and the cortical bone thickness.

From the results of our study, we suggest placing a pilot-drill , when the smaller diameter MSI's (1.2mm, 1.3mm) are chosen for sites having narrow inter-radicular spaces and dense cortical bone thickness (2mm – 3mm). This would prevent the build-up of increased torsional stresses and friction between the cortical bone and the MSI and hence prevent the failure of the self-drilling MSI's.

The risk of fracture is greater, if a miniscrew implant with a smaller diameter is placed, without drilling a pilot hole, in areas of thick cortical bone and high bone density.

In-spite of the 4% incidence of fracture reported in the literature, our study only found 2.6% incidence of fracture, the probable reason could be that our study was an in-vitro study and factors such as method of insertion (using torquimeter guide) and variability in the bone properties (using synthetic bone) were controlled in our study. But when we extrapolate this in clinical situation with the variability in host factors, operated related factors and the bone related factors, it might lead to increased incidence of fracture. This in-vitro study documents a strong correlation between the maximum insertion torque and the diameter of the MSI.

The larger diameter MSI's (1.4mm, 1.5mm) showed dimensional changes such as fatigue striations at the tip, thread and shaft core, blunting of the MSI tips and threads. Even though the larger diameter of MSI's showed surface dimensional changes at the tip, they showed significant fracture resistance on insertion into different cortical bone thickness.

The possible reason for the increased resistance to fracture and failure of the larger diameter MSI's could be attributed to its increased diameter, in-spite of increased insertion torque values which are well within the range as recommended by **Motoyoshi et al** [67]**.**

The results of this study show a direct relationship between peak insertion torque value at fracture and miniscrew diameter, with the largest-diameter screw emerging as the strongest and the smallest diameter screw as the weakest.

This was validated by an in-vitro trial of MSI's with diameters of 0.8 to 2.0 mm by **Johansson et al** [43] where he reported that the MSI's diameter was the major predictor for holding and breaking strength. He also emphasized that the larger the diameter of the MSI's, the better its holding strength in thick bone.

Choi et al and Cha et al [17] after evaluating the retrieved MSI's reported that only a thread edge closer to the tip of the used anodic oxidized miniscrew became smooth by smearing. A thread edge close to the tip of the used machined surface miniscrew became rough, compared with the unused machined surface miniscrew.

Hence, results of our study was in accordance with the study by **Choi et al** [17], reporting that all the MSI's which showed dimensional changes had structural surface dimensional changes at sharp cutting edges of its tips and threads.

These surface dimensional changes at the tip could be due to, either the tip design and/or stress experienced upon insertion into thicker cortical bone. Because a self-drilling type miniscrew implant tip had the form of a sharp point to increase the cutting force below the cortical tissue. Stress was concentrated in the tip area when the insertion process occurred, so the tip area was more vulnerable than other parts of the MSI. This in-vitro study documents a strong correlation between the maximum insertion torque and the diameter.

Many times during the orthodontic treatment, when a miniscrew implant fails, the re-installation of same MSI after sterilization is required in same patient, either in the same area or in an adjacent area is required. Even relocation of miniscrew implants to a better position may also be necessary in certain clinical situations. MSI strength could also be affected during procedures of repeated removal and insertion of MSI, which might lead to fatigue within the MSI resulting in fracture.

As the self-drilling MSI of smaller diameters studied shows variations at its tip, threads and core due to high insertion torque which may alter its surface properties, therefore requires pilot drilling of the cortical bone if miniscrew implants has to be re-used to resist MSI fracture. If pilot drilling is not performed, the risk of failure by fracture of the miniscrew implant increases.

This in-vitro study documents a strong correlation between the maximum insertion torque and the diameter of the MSI.

Cortical bone thickness:

The results of this study on evaluation of the dimensional changes of MSI's on insertion into different cortical thickness showed, as the varying diameters of MSI's were inserted into increasing cortical bone thickness, the MSI's showed increase in the surface dimensional changes. This in-vitro study documents a strong correlation between the maximum insertion torque and the cortical bone thickness.

When the varying diameters of MSI's were inserted into 1mm cortical bone thickness, surface dimensional changes such as fatigue striations were observed. The surface dimensional changes observed when the MSI's were inserted into 1mm cortical bone thickness were not significant.

One possible reason could be that the mean peak insertion torque value of 7.667Ncm observed for the MSI's inserted into 1mm cortical bone thickness is well within the range of the recommended torque value of 5Ncm – 10Ncm by **Motoyoshi et al** [67]**,** so there would not have been any undue torsional stresses developed during insertion. Hence, the 1mm cortical bone thickness did not induce any significant surface dimensional changes of the MSI's.

When the varying diameters of MSI's were inserted into 2 mm cortical bone thickness, dimensional changes such as fatigue striations, blunting of the sharp cutting edges of MSI tips and threads, and distortion or bending were observed. Even though the 2mm cortical bone thickness did not induce any fracture of the MSI's, there was distortion or bending of two MSI were observed.

One possible reason for the distortion or bending of the one MSI reported could be that, the peak insertion torque value of the deformed MSI was 10Ncm, and this insertion torque value was higher than the mean peak insertion torque of 9.06Ncm recorded for the 2mm cortical bone thickness group. This peak insertion torque value was in the highest range of the recommended torque value by **Motoyoshi et al** [67], and there could have been increased friction between the cortical bone and the MSI as reported by **Chen et al** [14]**.**

When the varying diameters of MSI's were inserted into 3mm cortical bone thickness, dimensional changes such as fatigue striations, blunting of the sharp cutting edges of MSI tips and threads, distortion or bending , and fracture of the MSI's at the thread – shaft interface were observed.

One possible reason for the fracture, distortion or bending of the MSI's reported could be that, the peak insertion torque values measured during bending or distortion of the MSI's were 10.4Ncm, 11Ncm, 11.9Ncm, 11.8Ncm, and these insertion torque values were higher than the mean peak insertion torque values of 10.64Ncm observed in our study, and higher than the recommended torque values of **Motoyoshi et al** [67]**.** The peak insertion torque values recorded during fracture of the MSI's were 13.4Ncm and

13.28Ncm, which were both higher than the mean peak insertion torque value and the recommended torque value by **Motoyoshi et al** [67].

Heidemann et al [37] reported the increase of peak insertion torque values and shearing forces on the screw itself causes fracture of the screws in thick cortical bone in their in-vitro test. These findings by **Heidemann et al** were in accordance with our results.

Chen et al [14] reported that, the increased torque should have been because of the dense cortical bone which produced a large amount of friction between the cortical bone and the MSI, and hence the shearing force would have been large. The results of our study were in accordance with the results of **Chen et al and Choi et al** [17].

Jolly and Chung et al [44] reported that, if there is an overly high insertion torque recorded more than the range the MSI can withstand, they will cause breakage of the MSI's.

Whang et al [92] reported that thick cortical bone with a high bone density may constitute a risk for miniscrew implant fracture especially if a self-drilling MSI with a smaller diameter is used.

The results of this study was in accordance with the studies by **Jolly et al** [44] and **Whang et al** [92] who reported that both the thick cortical bone and the high insertion torque will lead to failure of the implants.

Whang et al [92] has recommended two strategies to avoid high insertion torque, which could lead to MSI fracture, either by using a torque limiting screwdriver or pre drilling pilot holes in areas where thick cortical bone can be expected.

Chen et al [14] reported that, even though SDIs have many advantages, if the bone is dense, they should not to be chosen, as they might lead to failure of the MSI's. STIs should be considered instead. In the maxilla and areas with thin cortical bone in the mandible, MSI's would penetrate easily. Failure due to stripping of bone was infrequent, so pilot drilling was not necessary, and this was in accordance with our findings.

This in-vitro study documents a strong correlation between the maximum insertion torque and the diameter of the MSI and there is also a strong correlation between the maximum insertion torque and the cortical bone thickness.

So we recommend placing a pilot-drill, when the smaller diameter MSI's (1.2mm and 1.3mm) are chosen for sites having dense cortical bone thickness (2mm and 3mm). This would prevent the buildup of increased torsional stresses and friction between the cortical bone and the MSI, hence preventing the failure of the MSI's.

To reduce insertion torque and minimize the risk of MSI fracture, it is advisable to weaken the cortical bone by pilot drilling in thick cortical bone and high bone density.

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SUMMARY AND CONCLUSION

Effective anchorage by miniscrew implants has achieved widespread acceptance in orthodontic treatment. However, miniscrew implant failure remains a concern in orthodontics. One of the types of failure is the fracture of miniscrew implants. It occurs during insertion or removal, but can also happen during excessive force application for orthodontic treatments. The most common reason for MSI fracture is due to increased torsional stresses that develop during its insertion. The bone quality and density can also influence insertion torque resistance, and when associated to sub-perforation can increase incidence of fracture.

In spite of the adequate literature, many doubts still exist regarding how certain morphological changes reflects the mechanical properties of MSI, consequently leading to dimensional changes, distortion and fracture, which are a potential risk.

However, there are not enough studies which have evaluated the effects of the dimensional changes of these MSI's when inserted into different cortical bone thickness and varying densities, so there is a need for evaluating such dimensional changes of MSI, at their tip, shaft, and head to know its mechanical limitations and to interpret their clinical applications.

Hence this study was done to evaluate the peak insertion torque of varying diameters of miniscrew implants in different cortical bone thickness and to assess the dimensional changes, distortion and fracture of the retrieved miniscrew implants.

Results of this In-vitro study documents the correlation between the maximum torque and diameter of MSI.

Conclusions drawn from this study are,

1. An increase in the diameter of the MSI plays a significant role in increasing the peak insertion torque values of the MSI's. There was a significant difference in the peak insertion torque values between the varying diameters of the MSI's. As the diameter of the MSI's increased there was a proportionate increase in the peak insertion torque.
2. An increase in the cortical bone thickness plays a significant role in increasing the peak insertion torque values of the MSI's. There was a significant difference in the peak insertion torque values between the different cortical bone thickness. As the thickness of the cortical bone increased there was a proportionate increase in the peak insertion torque.
3. The retrieval analysis by scanning electron microscope showed that, the smaller diameter MSI's (1.2mm, 1.3mm) inserted into thicker cortical bone (3mm) showed increased surface dimensional changes, distortion and fracture. The peak insertion torque values recorded for

the distorted and the fractured MSI's were higher than the mean peak insertion torque values recorded.

4. This in-vitro study documents the correlation between the maximum torque and diameter of the MSI and it also documents the correlation between the maximum insertion torque and the cortical bone thickness.

Hence from the results of our study it can be concluded that, when using smaller diameter MSI's in regions of dense or thicker cortical bone such as the posterior mandible or mid-palatal region, it is necessary to use a pre-drill in-order to reduce the peak insertion torque and hence prevent dimensional changes and fracture of the MSI's due to excessive torque and therefore aid in maintaining the ideal torque range.

In-spite of the 4% incidence of fracture reported in the literature, our study only found 2.6% incidence of fracture, the probable reason could be that our study was an in-vitro study and factors such as method of insertion (using torquimeter guide) and variability in the bone properties (using synthetic bone) were controlled in our study. But when we extrapolate this in clinical situation with the variability in host factors, operated related factors and the bone related factors, it might lead to increased incidence of fracture and distortion of MSI's. Hence this study was done to evaluate the dimensional changes of MSI's and help the clinicians to know the mechanical limitations of the MSI's inserted into different cortical bone thickness.

Orthodontists should not only be aware of the size and torsional strength of miniscrew implants but should also consider the host factor, especially the cortical bone thickness and its density while placing the miniscrew implants.

When the treatment plan orientates the placement of lesser diameter self-drilling miniscrew implant in narrow inter-radicular space, high bone density and thick cortical bone regions, it is worth using a pilot drill, thus reducing the possibility of miniscrew fracture.

The primary limitation of this study pertains to the inability to directly transfer the effects identified into the clinical situation. While the synthetic bone used in the present study is well suited for controlling extraneous factors and focusing on the effects under consideration. Experimental findings should be compared to clinical studies. In vitro measurements tend to more accurately describe the variable tested; however, they are far from simulating the actual clinical conditions. Clinical studies on the other hand, may report clinically applicable data, but do not provide an insight into the specific details of the research hypothesis.

So, the clinicians must know the properties of miniscrew implants in order to increase the success rates of their procedures.

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