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Horizontal Buccal Cortical Bone Thickness for Miniscrew Placement Strategies

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ABSTRACT

PARICK HOLMES. Horizontal Buccal Cortical Bone Thickness for Miniscrew Placement Strategies.(Under the direction of Dr. Jing Zhou)

Introduction: Miniscrew implants or MSI's are reported to be used by upwards of 80% of orthodontists today, and failure rates can reach as high as 30%. The aim of this study was to identify horizontal buccal cortical bone thickness patterns in the maxilla and mandible and to create MSI placement strategies based upon the identified pattern. **Methods:** Fifty randomly selected cone beam computed tomography scans or CBCT's from healthy subjects with intact dentitions were studied using one quadrant from a maxillary arch and one from the mandibular arch. 900 maxillary and 900 mandibular cortical bone thickness measurements were made. Measurements came from 3 mesio-distal locations at levels of 4mm and 6mm from the alveolar crest in 3 different regions per arch. **Results:** Cortical bone thickness levels are significantly thinner at a point bisecting 2 teeth (maxilla 1.19mm and mandible 1.26mm) than the bone adjacent to the teeth (maxilla 1.29mm and mandible 1.19mm) in both arches. Maxillary cortical bone (1.26mm) is significantly thinner than mandibular cortical bone (1.34), and in the mandibular arch it tends to get thicker as you move posteriorly. (1.24mm, 1.36mm, and 1.43mm) The maxillary buccal cortical bone did not increase in thickness as you progress posteriorly (1.26mm, 1.27mm, 1.26mm). The 2 sites with the greatest percentage of measurements less than 1mm (20%) were in the mandible bisecting the canine and premolar at 4mm and 6mm from the alveolar crest. The site with the highest percentage of measurements greater than 1.5mm (50%) was also in the mandible adjacent to the first molar at 6mm from the alveolar crest.**Conclusion:** Cortical bone thickness is significantly thinner centrally between two teeth when compared to areas adjacent to roots. Cortical bone thickness tends to only exceed the upper limit of what is considered ideal in the posterior mandible between the second premolar and first molar.

INTRODUCTION

Orthodontic miniscrew implants, or MSI's are reported to be used by upwards of 80% of orthodontists today.[1] They offer a valuable anchorage option that allows orthodontists the ability to offer treatments that were once considered difficult or even impossible. Due to how little is known about MSI's and their success, orthodontists may be placing them without giving thought to where or how they should by placing them, and may be overlooking placement in an area that can offer a higher success rate.

It has been reported that failure rates for MSI's can reach as high as 30%.[2] One of the most important factors in determining MSI stability and success is the thickness of the cortical bone in which the MSI is being placed.[3] Unlike the endosseous implants used in prosthodontics, MSI's do not osseointegrate, so it is the quantity and quality of bone at the insertion site that will help determine its stability and success.[4,5,6] Compared to cancellous bone, cortical bone has a higher modulus of elasticity, making it more resistant to deformation, and superior for anchorage.[7] Differences in cortical bone thickness as small as .5mm have been shown to have a major impact on success rates.[8]

Cone Beam Computerized Tomography has been shown to be an accurate tool for measurements that other imaging methods are unable to reproduce.[9] By employing CBCT software to evaluate bone characteristics, much can be learned about why MSI failure rates are so high, and what can be done to lower that failure rate. The use of CBCT's has shown to be far superior than any other radiograph for this purpose.[10]

In previous studies, there has been a lack of continuity in where exactly measurements have been taken. In particular, the mesio-distal (horizontal) location has not been addressed. When choosing cortical bone measurement sites in the A-P direction, some chose to measure from the area between teeth that appears to have the thinnest cortical bone without identifying where this was[11], some bisect the area and take their measurements from the middle[12], however most studies fail to mention from where the measurements were exactly taken.[6, 13, 14] To date, no other research has focused on differences in cortical bone thickness from the proximal surface of 2 teeth, to a point bisecting the 2 teeth. With as much knowledge as we have regarding cortical bone thickness in the vertical dimension, little is known as to whether or not cortical bone thickness (and in turn MSI success rates) can be affected by your mesio-distal site selection between teeth. There are currently no recommendations for A-P positioning strategies of MSI placement in between teeth.

By being able to predict the cortical bone characteristics in different individuals in different locations, the orthodontist would be able to more effectively select the most ideal location to place an MSI to maximize effectiveness and minimize chances of failure. It has been reported that an MSI site will take 3-6 months to heal, meaning that failure would either require that amount of time to heal before placing the MSI back in the same location or require selecting a new and less effective or efficient location.[15] If failure rates can be improved based on knowledge of bone in certain areas, more orthodontists may become comfortable with using them, and more difficult treatments have the potential to be treated with a better outcome. Because of the lack of continuity in measurement sites in previous research, the practitioner is unable to know precisely what to expect from cortical bone thickness levels because of variable mesio-distal placement positioning, By knowing cortical bone trends as you approximate the tooth at various levels both vertically and horizontally, the orthodontist would be able to maximize their chances for success based upon what is already known about cortical bone thickness and how it relates to success.

My Hypothesis

As the clinician approximates a tooth, there is a greater likelihood that they will attempt to increase the angle of placement to avoid root contact and thus increase the amount of cortical bone that the MSI would penetrate through. If that increase is substantial enough, it would introduce excess heat and torque during insertion to a critical level that could increase the likelihood of failure. To date there are no placement guidelines for mesio-distal positioning of an MSI in between two teeth, and no known horizontal cortical bone thickness patterns to influence those guidelines.

My null hypothesis is that buccal cortical bone thickness does not increase a clinically significant amount as you approximate a tooth when compared to a point bisecting the two adjacent teeth. By being able to predict the cortical bone characteristics through CBCT evaluation in different individuals for different locations, the orthodontist would be able to more effectively select the most ideal location to place an MSI to maximize effectiveness and minimize chances of failure.

REVIEW OF LITERATURE

Prevalence of MSI's

Whether they are called temporary anchorage devices (T.A.D.'s), mini-implants, orthodontic mini-implants (OMI's), miniscrews, or miniscrew implants (MSI's), small titanium implants have become an overwhelming presence in the orthodontic community. Why are MSI's being discussed so much and why are people using them? They offer an anchorage option that at one time was not possible. MSI's have been commonly recommended for cases with difficult anchorage, poor patient compliance, or cases previously thought to be only treatable through surgery or extraction. It has been suggested that MSI's can be used for Class II distalization, posterior intrusion for open bites, anterior intrusion for vertical maxillary excess, to correct canted occlusal planes, to upright molars, protract molars, or any time absolute anchorage is needed. [16] Group distalization of mandibular teeth, a treatment option rarely attempted has also been reported and suggested through MSI anchorage.[17] In the past, extraoral anchorage through a headgear may have been the only option to increase anchorage and prevent reciprocal movement in a difficult case. Without patient compliance, the only way an objective like this could be reached would be with the aid of an MSI.[16] Good anchorage ensures that teeth move predictably and without any unwanted reciprocal movement.[2] Stable anchorage is one of the most important requirements for successful treatment. In the case of a periodontally compromised or mutilated dentition, available anchorage is often limited or nonexistent. In the past this has lead to compromised treatment plans and increased treatment times. MSI's broaden treatment options in adults.[3]

It is clear that MSI's are commonplace today, but how many practitioners are actually making use of these broadened treatment possibilities? In a 2008 survey, Buschang found that 80% of the 564 AAO member respondents acknowledged having at least one MSI in an ongoing case.[1] More recently, a 2010 survey found that 91% of orthodontists had at least one case going.[18] Although fewer than half reported their ultimate treatment times being faster, 78% of those individuals reported that the MSI's had made their treatment better and were satisfied with their use. Despite 91% of all respondents reporting no training in this field during their residencies, and 13% saying that they still have not been adequately trained, 91% reported that they still plan on using MSI's in the future. [1] There are several reasons that people have chosen to not use MSI's within their practice. Concern for root damage, increased chair time, lack of significant treatment result difference, not wanting to administer anesthetic, or lack of training have all been reported as being factors.[1, 18] Despite these fears being common, the most common problems encountered with MSI placement were not any of these, but instead screw loosening and tissue irritation.[18] Of those who do use them, most never drill pilot holes, never measure insertion torque, load them immediately, do not measure force applied, and use indirect anchorage only.[1] Some have recommended that placement planning should go as far as to prepare surgical stents with embedded wires and multiple radiographs to verify proper location prior to placement.[19] It is clear that despite the overwhelming popularity and reported success and satisfaction with their use, there is a generalized lack of planning that goes into their placement, and they are not used to their full potential. Given the lack of planning that goes into placement, compared to the planning recommended for placement in the literature, it is not surprising that failure rates are high, and many choose not to use them.

The role of CBCT's in MSI research

The use of radiographs in preparation for placement of a dental implant is not a novel concept. The use of pretreatment panoramic and periapical radiographs has been suggested even though there is known distortion and magnification associated with traditional films. [20,21] It is also a recommended practice to take radiographs post-insertion to verify proper placement, thus exposing the patient to unnecessary radiation.[19] By taking advantage of current radiological technology and applying that knowledge to our MSI planning, we may be able to eliminate the need for unneeded radiation exposure. CBCT technology has been shown to be very accurate and reliable. Many studies have found that both CBCT measurements, and caliper measurements were very reliable and there was statistically no significant difference for single measurements between what was shown in a radiograph and what the true anatomy was.[9,22, 23]

Common Placement Sites

Just as anchorage needs differ from person to person, the location to place an MSI can vary greatly. This however does not mean that all areas are safe for placement. For buccally placed MSI's, it is generally accepted that mesial and distal to first molars is a safe and effective area for placement. [14, 24-27] Although placement sites around premolars have also been shown to be successful, many studies have selected more posterior locations due to the increased interradicular space giving more placement selection.[6, 25, 26] In the maxillary arch, the largest interradicular spaces have consistently been reported between the second premolar and first molar. It is suggested that interradicular space increases apically and posteriorly, and those are the most ideal areas for placement.[26, 28, 29] From the lingual aspect of the alveolus in the mandibular arch, it is generally agreed upon that MSI's are not well suited, however in the maxillary arch if placed 1-2mm from the mid palatal suture or in the alveolus mid root, they offer stability without risk of contacting roots. [7, 30, 31] The areas immediately adjacent to teeth are not the limits to where MSI's have been attempted. Other sites include the zygomatic buttress, the retromolar pad, as well as the use of miniplates placed apical to the teeth beneath the unattached tissue. [29, 32, 33] Despite the success of surgically placed temporary anchorage devices, MSI's placed without a surgical procedure have a high enough success and lower associated pain levels. By adding a surgical procedure to the placement of an MSI, the ease of placement is eliminated. [29, 32]

In addition to tooth site selection, much attention has also been paid to the levels at which MSI's should or should not be placed. It is generally agreed upon that there will be better long term success when placed in the attached gingiva. [5, 14, 16, 24, 34, 35] Despite this being variable from patient to patient, some have indicated that on average this means that an MSI cannot be more than 4-5mm from the gingival margin in the maxilla, or 3mm from the gingival margin in the mandible.[24] From a bone-stability standpoint, it has been shown that favorable bone levels can be found in both the maxilla and mandible and at varying levels from 2-6mm from the alveolar crest and from the distal of the canine to the mesial of the second molar. [13, 24, 25, 36]

Other Guidelines

If preparation for placement of an MSI is so important, then the variables other than where to place them must be accounted for. It is generally accepted that a titanium MSI with a cutting thread, conical shape, small diameter over 1mm, and a length of 6-8mm is ideal. [5, 26, 37-41] Appropriate force levels between 100-200g immediately placed on the MSI have been shown to be successful as long as they are mechanically setup in a way that will not unscrew the MSI, and are not positioned away from the MSI bone junction far enough to create a moment due to a large lever arm.[2, 4, 38, 39, 42, 43] Placement torque levels between 5-15 NCm have shown a trend for producing higher success rates,[2, 34, 44, 45] and placement in cortical bone at a minimum thickness of 1mm has been recommended. [45] Although widely disputed, various angles of insertion have also been recommended aimed at maximizing cortical bone contact of the MSI. [46-48] With so many factors having an impact on success, is important to have knowledge of different placement sites for proper placement planning.

MSI Success Rates

Recent Literature has reported success rates ranging from as low as 67% to a high of 97%.[2, 39] For an MSI to be considered successful, it must remain stable for the duration of treatment where it will be loaded.[45] In some research it has been defined as having survived 6 months of treatment without loss or mobility, but even in these cases, it can be assumed that no changes would have occurred in the stability if continued use was required beyond 6 months.[2] Stability and success does not necessarily mean that the MSI's remained stationary. One study in particular found that MSI's placed in the zygomatic buttress tipped forward between .4mm and 1.5mm with the application of a niti coil spring.[33] Success is related to the ability to use the MSI in treatment without failure of mechanics used. Despite the success rates being so variable through literature over time, a recent survey found that the vast majority of respondents reported success rates around 75%, attributing most failure to lack of experience (technique). Those that planned their insertion with the aid of radiographs had a higher success rate than those who did not. The same was true for practitioners who measured insertion torque during the procedure. Perhaps the most interesting point illustrated in the survey was that the failure rates were significantly lower for the orthodontists who placed their own MSI's versus referring them to oral surgeons or periodontists for placement.[1] Various factors have been studied and linked to success or failure. Factors such as technique, insertion angle, time waited until loading, mechanics used, force levels applied, type of tissue placed through, whether or not a pilot hole was used, MSI design, age, sex, torque at placement, root proximity, bone quantity and quality at the site of placement, and even mandibular plane angle. [2, 4, 5, 8, 24-26, 29, 34, 35, 37, 39, 42, 45, 48, 49] With so many reported causes of failure, it can be concluded that there is no single contributing factor causing failure. The magnitude of research in this field has given us indications of what may lead to more of a chance of failure, but it is still unclear.[50] With so many factors coming into play, it becomes essential to identify what the common factor that each of these individual factors are inherently linked to. In the end, the factor that is most intimately associated with success and failure is bone biology, and in particular cortical bone that dictates stability.[3, 35, 45]

Cortical Bone and Stability

Before understanding how various factors relate to cortical bone, it is important to understand what cortical bone is and why it is related to stability. Bone within the jaws typically involves a thin layer of cortical bone surrounding trabecular or cancellous bone. Cortical bone has a higher modulus of elasticity than the trabecular bone that it overlays. The cortical bone is stronger and more resistant to deformation resulting in the ability to bear more load than trabecular bone and therefore, the more cortical bone, the greater the mechanical stability.[13] Compared with cortical bone, cancellous bone contributes much less to stability.[7] Studies have shown that as little as 5% bone to implant contact is required for resistance of orthodontic forces. This means that thicker cortical bone will result in more bone contact at the junction of the MSI and bone.[39]

There are essentially 2 phases of stability completely independent of one another yet intimately tied to the success of an MSI.[45, 48] Primary stability, or stability immediately after placement of an MSI is based upon bone quantity, implant design, and methods used to place the implant.[3] It is a function of mechanical retention of the MSI in the bone.[4, 45] Secondary stability is responsible for implant stability and success after the initial healing period as well as for most of the loading period. It has been reported that within 2 months of placing the implant that the bone within 1mm of the implant will have completely turned over.[6, 45] Ure (2011) indicated that the ultimate cause of implant failure is loss of bone to implant contact which changes throughout the primary and secondary phases of stability. This study reported that there is a gradual loss of primary stability that is taken over by secondary stability in about 3 weeks time after placement. In other words, all implants begin to show increased mobility in the first 3 weeks.[35] At 3 weeks time, the bone at the interface is primarily woven bone. Those implants that failed showed a greater increase in mobility in the first 3 weeks than the ones that were successful. [39] Secondary stability levels out after the 5th week and remains constant for the duration of treatment.[35] Secondary stability, or bone formation and remodeling at the interface of bone to implant is the result of the individual's response to the implant. Without successful primary stability, the implant will not succeed long enough to develop secondary stability.

Placement Factors Related to Cortical Bone Thickness

Insertion Angle

It has been suggested in the literature that the more cortical bone that an implant passes through, the thicker the implant, the more torque that is generated, and the more primary stability that is achieved. It was then concluded that by varying the angle of insertion of an MSI, you can control and maximize the amount of cortical bone that the implant passes through.[47, 48] Despite these reports, some studies have also found that the most stable orientation was 45° and in the direction of force application, followed by 90° to the bone.[51] They recommended that because small interradicular spaces would make it difficult to place a tad in the direction of force application, then all MSI's should be placed 90° to the bone.[51] Contrary to this, it has also been shown that implants placed at 60 and 120° to the bone surface are both equally stable to an activated 2N nickel-titanium coil spring, and both significantly more stable than one placed at 90°.[46] To muddy the waters even more, in 2008 Wilmes found that the highest insertion torque (reflecting cortical bone quantity and stability) was highest at a 70° angle and lowest at a 30° angle.[48] It is clear that there is no consistent message about the angle at which the MSI should be placed. It has even been reported that when an attempt has been made to avoid roots by angling an MSI in a horizontal or vertical direction, the MSI was in fact no further away from the roots than those that were not angled. The only consistent finding was that the smaller the insertion angle, the greater the cortical bone thickness, and the further the MSI was located from the roots of adjacent teeth, the greater the success rate.[52] Whether controlled or not, the technique and planning that goes into placement of the MSI can positively or negatively impact stability and ultimately success. In other words, if your technique is flawed, you may introduce unwanted changes in the cortical bone thickness of your placement site by altering the angle of insertion.[39] By inserting an MSI at an angle of 30°, bone contact will increase by a factor of 1.5x.[47]

Immediate Loading vs. Healing Period

There is no shortage of literature offering suggestions on the appropriate amount of time to wait before loading an MSI. Many say that immediate loading has no effect on long term stability.[31, 38, 39, 43] Others say that as long as appropriate and typical orthodontic forces are used, they are within the range of what an MSI can remain stable for during its primary stability.[42] And at the other end of the spectrum, there are those who say that healing time would be ideal prior to loading to allow secondary stability to take place.[27, 40] In 2003, Deguchi placed 96 titanium implants in canine subjects and loaded them at 3,6, and 12 weeks. It was concluded that because no MSI's failed at the 3 week interval, then perhaps no healing time is necessary because at 3 weeks the bone is primarily only woven bone at the interface. It is not until the 5th week that secondary stability becomes the main source of retention. Therefore, those that were still successful at 3 weeks were still only retained due to primary stability.[39] Motoyoshi on the other hand found that healing time is essential, but only in younger individuals. In his study, he found that in an early load group with adolescents, the success rate was significantly lower than that of the late load group. Upon closer examination, he found that the success rate was not significantly different in the adult early vs. late load groups, however the success rate in adolescents was the highest in the study (97.2%) when a 3 month healing period was allowed.[2] It is no coincidence that it has also been reported that if an MSI was lost, then a 3 month healing period would be required before the cortical bone would have undergone enough repair to tolerate the reinsertion of an MSI and be stable. It is critical to know if orthodontics forces will compromise stability.[15] Some would argue that typical orthodontic forces cannot cause an MSI to fail by compromising its primary stability. In other words, because of the light nature of typical forces, if you have enough primary stability from cortical bone, then you should not need healing time prior to loading.[42]

Mechanics and its relationship to cortical bone

It is not enough to insert an MSI at the right angle, or wait the appropriate amount of time prior to loading it. It is imperative that the mechanics employed are ones that are clinically effective and not deleterious to the success of the MSI. It has been found that large lever arms, excessive forces, and mechanics that create a moment unscrewing an implant can lead to greater failure rates.[3, 4, 31, 42, 53] Forces for MSI's should not be different than typical forces used in orthodontics. 100-200 grams of force is adequate to achieve most orthodontic tooth movements without disrupting the stability of an MSI.[2, 3, 48, 54] The relationship between mechanics and cortical bone thickness can also be applied to angle of insertion. The smaller the angle (the more oblique the placement), the more cortical bone is passed through, and the further the head of the MSI will be located away from the bone.[48] The further an MSI sticks out from the bone, the larger the lever arm, the greater the risk of failure. It can also be drawn from this that if cortical bone is too thick, and high torque levels prevent full insertion of an MSI, then the practitioner would be forced to use larger lever arms that could in turn result in failure.[3]

Keratinized Vs. Non-Keratinized Tissue

Cortical bone is similar as you go from attached keratinized tissue to non-keratinized tissue.[39, 49] It is not the quality of cortical bone associated with overlying tissues that affects the stability, but rather the bony response to placing MSI's in different tissues. In multiple studies, all failed implants happened to be placed in non-keratinized tissue, whereas successful implants were placed in keratinized tissue.[34, 35] Miyawaki reported that failure is 4x as likely with irritation from placement in non-keratinized tissue.[5] Placement in attached gingiva allows for less discomfort, less tissue overgrowth, and less movement from pulling tissues.[16] Recently, it has been hypothesized that it is not the keratinization dictating success, but rather whether or not the tissue is attached and how attached it is. The more unattached the tissue is and the more movement that the tissue undergoes during function, the more likely it is that it will introduce inflammation, cause peri-implantitis, and loss of primary retention. This study actually found that tissue immediately adjacent to the mucogingival junction was not very mobile, and was suitable for MSI placement. They recommend placement in tissue keratinized or non-keratinized as long as you do not stray too far from the mucogingival junction.[54]

MSI Design

There are countless factors associated with the design of an MSI that relate to its success in the oral environment. Length is a characteristic that although is important in terms of having enough available buccal-lingual width for placement, does not in fact influence stability. The most important characteristic affecting stability is implant diameter and not length. It is the amount of cortical bone penetrated, and not depth of trabecular bone.[55, 56] Although there is a large range of suggested diameters being at least 1.2-1.3mm and up to 1.6mm, there is much more concise agreement upon the diameter being no smaller than 1mm. [2, 5, 16, 26, 38, 41] Conical shape with wider diameters means higher torque and higher primary stability.[41] In some studies, diameters of 1mm or less had very limited success if any.[5] When an MSI is placed into 1mm of cortical bone, it is only the cortical bone that is stressed and dictates stability. In one study, when that amount of bone was doubled, it was found that the stress was still felt only through the cortical bone and did not change the stresses felt on cancellous bone. The only time that stresses are felt in the cancellous bone is when there is insufficient cortical bone to maintain the MSI. This demonstrates that an increased amount of cancellous bone contact has no effect on stability.[55]

Age and sex

As individuls age, their bone undergoes a transformation. This includes both cortical and cancellous bone. As children mature, so does their bone, creating a more dense bone. At some point the bone mineral density peaks, and will again begin to decline. It has been found that bone mineral density begins to decrease in women around age 40, and even younger in men.[57] In 2007, Motoyoshi found that in early loading groups, adolescents had a success rate nearly 30% less than adult counterparts.[2] Lee also found that those under age of 20 had a significantly higher failure rate. In 2010, Motoyoshi found that placement torque was lower in older people in a study population ranging from 13-64 years.[44] It has already been discussed that MSI stability is a factor of not just quantity of bone but also quality. As bone mineral density increases into adulthood and then decreases, our primary stability can be expected to increase into adulthood, and then begin to decrease somewhat as we age. Similarly, if a person develops osteoporosis, or any other condition affecting bone density, then we can expect lower primary stability. Recent studies have attempted to qualify the density of bone in CBCT's by use of Houndsfield unit measurements. Although this is a relatively unexplored area of the research, it is being reporting as a legitimate tool in evaluating bone for the placement of MSIs.[58] Sex on the other hand has shown very little evidence for having an impact on stability or success rates. [14, 49, 59] There are studies that have suggested thicker cortical bone thickness in adult males versus females.[11, 24]

Torque and pilot holes

Perhaps the factor most intimately related to cortical bone is torque. It also happens to be one of the most heavily published areas in MSI research. It is well known that cortical bone thickness has a direct relation to insertion torque, and that the higher the torque, the more mechanical interlocking and higher primary stability. [2, 34, 44, 45, 48, 60, 61] Although an increase in torque means increased stability, too much torque introduces other factors that can increase failure rate. Bone compression, damage from heat, and trauma to tissues interfering with bone turnover can prevent secondary stability and lead to a decreased success rate.[45, 60, 62] Karmani reported that even in 500bc Hippocrates was aware of the danger that heat can play on bone health when drilling and referenced his advice to cool drills with cold water. Although it is not completely understood what happens, increased torque is associated with increased heat, and potentially results in vaporization and dehydration, desiccation, shrinkage, membrane rupture, and carbonization. Karmani reported that bone is a poor conductor of heat, and temperature from friction can rise sharply. Heat can be influenced by how sharp the cutting edge is, diameter of the implant, force of application, and speed of drilling.[62] It has been reported that even at 350 RPM with a non cooling drill the human femur reached temperatures of 90°C or 194°F. Bone alkaline phosphatase denatures at temperatures above 56°C, and collagen denatures at 60°C. Because cortical bone is denser than trabecular bone, it has more of a temperature increase with friction. In other words, it is very easy to quickly raise the temperature of cortical bone during the drilling process, and caution must be observed.[62, 63]

If torque is of such high importance in determining the success or failure of an MSI, then what is the proper torque that should be used? It was already discussed that those orthodontists who monitor their torque insertion have higher success rates than those who do not.[1] Although a large spectrum of torque values have been associated with success, the most commonly reported range is 5-10NCm.[2, 3, 34, 44, 45, 60] Torque values too low will result in inadequate primary stability, and torque values too high can result in trauma to tissues resulting in lack of secondary stability.[45] Torque values as low as 22NCm have been reported to cause facture of the MSI, however more popular brands of MSI's have fracture levels between 30-35NCm.[64] There is more of a consensus on the lower limit of torque values, and success rates have been reported being high as high as 14-15 NCm.[34, 60] It is recommended by many that in cases where torque levels will be expected to be high, a pilot hole should be drilled measuring 65% of the diameter of the MSI. It was shown that cortical bone thickness levels of .5mm-1.0mm would be required to give insertion torques of 5-10NCm, whereas an area of 1.36mm thickness will result in 8.9 NCm torque with a pilot hole.[2, 3, 45]

Root Proximity

The further an MSI is placed from adjacent tooth roots, the higher the overall success rates.[10, 52, 65] Some even say that root proximity is more of a factor in MSI success than cortical bone thickness.[65] Due to anatomical differences, it is not always possible or easy to avoid adjacent tooth roots. It has been published that healing is variable, and even short duration damage can be permanent and not heal properly. Damage has been reported from point ankylosis and peri-radicular lesions requiring endodontic treatment to defects in the tooth, and MSI failure.[66] Other studies have shown that you can expect repair of the tooth (dentin and cementum), as well as periodontal tissues, and bone as early as 12 weeks later.[67-69] The best way to marry these conflicting reports is by qualifying the extent of the damage. As long as there is no inflammatory infiltrate, no pulpal invasion, or root fragmentation, the chances of significant damage are minimized.[68-70] This should not be a concern due to the fact that root contact during insertion has been shown to double the insertion torque, and raise it to a level that would clearly indicate a problem and notify the orthodontist that they need to reposition the MSI.[69] Even without damage to the individual structures, we can still have clinician placement error resulting in a failed MSI. By violating the pdl, there is a much greater chance at failure.[71-73] It has been recommended that a distance of .5-.6mm from implant to root will provide adequate space to prevent early failure.[16, 72] Assuming that the torque levels are monitored and maintained within the recommended levels based upon cortical bone thickness levels, we can assume that no significant damage is taking place, and chances of failure have been minimized.

Mandibular Plane Angle

When it comes to individual characteristics having effect on cortical bone and ultimately MSI success, form follows function. It has been reported that mandibular plane differences can impact the bony architecture of the mandible.[5, 74, 75] Wolff's law describes how bones model and remodel in response to mechanical and environmental influences.[74]

It has been demonstrated that the biting force of a hypodivergent patient is greater than that of the hyperdivergent individual, and that this musculo-skeletal classification results in thicker cortical bone and a thicker alveolus. Opposing this is the hyperdivergent patient with less biting force and smaller levels of cortical bone thickness. Not only do you need to know the regional characteristics of cortical bone thickness in a patient to predict cortical bone, but you also must take into consideration growth pattern.[5, 74, 75]

Cortical Bone Thickness Current Knowledge

Numerous studies have attempted to map the bone in the maxilla and mandible. Generally speaking, cortical bone increases in thickness as you move apically, and posteriorly. Mandibular bone is thicker than maxillary bone, and in the palate, cortical bone thins as you move posteriorly and laterally from the midline, and medially from the alveolus.[7, 13, 24, 26, 74, 76] Thickness ranges have been reported up to 2mm in thickness in the maxilla, and 3mm in the mandible.[13, 24] It has been shown that in order to gain sufficient primary stability, there needs to be at least 1mm of cortical bone present in an insertion site.[77] In order to maintain appropriate torque levels, the target thickness is between .5mm and 1.5mm, and on average 1.36mm of cortical bone will deliver 8.93 NCm when a pilot hole is used.[23, 45] The tolerance for torque levels without predrilling is much smaller and this makes it even more critical to know the thickness of the bone you are penetrating.

One of the most common sites for placement of an MSI is the buccal bone. In a comprehensive bone mapping study using CBCT scans of dry skulls, Baumgeartel found that there is adequate bone for placement of MSI's in any buccal region within the maxilla and mandible as long as you place the implant at the appropriate vertical level. The thinnest areas of cortical bone were located in the anterior maxilla and mandible, and in both regions, required placing the MSI 6mm apical to the alveolar bone to access thickness levels over 1mm. With the exception of the maxillary second molars, the bone progressively gets thicker as you proceed posteriorly meaning that there are several acceptable areas to place MSI's between the canines and second molars. Ideal areas for placement in the maxilla between canines and molars includes placement at 2, 4, and 6mm from the alveolar bone with the most ideal thickness being at the 6mm level.[45] Care must be taken to not go higher than this. By going 7-8mm apical to the bone, you risk entering the sinus, and this can result in development of sinusitis, mucoceles, and other complications. [47, 78] Ideal areas for placement in the mandible include the same mesio-distal placement at 2 and 4mm from the alveolar bone. If placing at 4mm the practitioner needs to be aware that the more posteriorly you go, the more likely that pre-drilling will be needed. 6mm levels were reported being so thick that placement would require predrilling once you moved distal to the first premolar.[13, 79]

Limitations of current research

Baumgaertel and Kim both identified that in the maxillary arch distal to the canines, the 4mm level is the thinnest, whereas mandibular bone gets progressively thicker from the bone crest and apically in all teeth. This knowledge is incredibly valuable for MSI placement planning, however there are certain locations that have yet to be studied thoroughly. It is likely that just as cortical bone can have vertical thickness patterns, they can have unique anterior-posterior/mesio-distal patterns. It is already well known that in general cortical bone gets thicker as you move posteriorly, however no one has ever addressed whether or not cortical bone gets thicker or thinner in between individual teeth. Different malocclusions require different mechanical setups for MSI's, and sometimes it can be advantageous to place the implant mesial or distal to the midpoint between two teeth. In the case of distalization, it has been recommended that by placing your MSI distal 1.5mm and angling it distally, you can maximize your distalization and not have to remove it once the premolars are retracted.[15] Just as form follows function, and different facial patterns can have different bone thicknesses, bone surrounding teeth may have different thickness than bone that does not surround roots.

With knowledge of teeth healing even after hitting a root, orthodontists may begin to feel more comfortable placing MSI's closer to teeth in areas they have not considered. Additionally, many orthodontists recommend diverging roots prior to placement which provides even more availability for different placement. Given the narrow range of acceptable cortical bone thicknesses and the placement preparation that must go into placing an MSI in an area where cortical thickness numbers are outside of that range (predrilling, angulation, etc), it would be of great benefit to know as much as possible about bony patterns in the maxilla and mandible. Areas that may have once been considered appropriate for placement may not be as you approximate adjacent tooth roots. Additionally placement sites that once may not have been considered ideal may be ideal if you were to place the MSI closer to the adjacent roots.

MATERIALS AND METHODS

Subject Population

Cone beam computerized tomography scans taken at the Medical University of South Carolina's James B. Edwards College of Dental Medicine were examined retrospectively using Anatomage 3D imaging software (Ver.5.0, San Jose, California) to evaluate the cortical bone thickness in areas commonly selected for mini-implant placement The scans were anonymous and had previously been screened by an oral radiologist to identify any possible pathology that would exclude the patient from the current study. The collection of CBCT scans includes contributions from all dental specialties. Not all patients were treated in the orthodontic clinic, and not all the patients needed orthodontic treatment.

Fifty maxillary quadrants and 50 mandibular quadrants were randomly selected from the radiographic database providing 1 maxillary quadrant and 1 mandibular quadrant from each subject to be analyzed. Either the right or left quadrant in each arch was analyzed based upon which one had a more complete dentition and healthier bony relationships. If both sides were suitable for the study, then a selection was made at random. This was justified by previous research which has shown there to be no differences in cortical bone thickness between the left and right sides of a patient.[76] Patient age, sex, and ethnicity were recorded if available to evaluate for any statistical significance. The scans were evaluated at a .33 voxel resolution.

The scans were selected with the following inclusion and exclusion criteria:

1. The entire maxilla and mandible are present in that quadrant's scan. The maxillary and mandibular arch will be from the same subject, however not necessarily from the same side.
2. There are fully erupted teeth and no impacted teeth in areas of interest
3. There is no more than 1 missing tooth per quadrant (excluding 3rd molars)
4. There is no pathology associated with the bone in the areas of interest. This includes presence of periodontal disease as diagnosed by loss in alveolar bone height.

Data obtained from the CBCT

The 3-dimensional scans were imported into Anatomage imaging software for analysis and measurements. All measurements were taken from an angle perpendicular to the bony surface as determined by Anatomage software. Measurements were made at levels of 4mm and 6mm apical to the alveolar crest. From a mesio-distal location, measurements were made at the most mesial and distal points between the teeth without violating PDL space, as well as a point bisecting the two previous points. The most mesial and distal points in-between the teeth were dictated by the narrowest interradicular space mesio-distally.

Measurements were made in each maxillary and mandibular quadrant at levels of 4mm and 6mm apical to the alveolar crest between:

a. Canine and first premolar (location A)

b. First and second premolars (location B)

c. Second premolars and first molars (location C)

This will provide a total of 6 measurements at each site, a total of 18 measurements per quadrant and a total of 36 measurements per subject.

Measurements will be identified by numbers 1-6 at each location:

a. Location 1: most mesial point at 4mm

b. Location 2: midpoint at 4mm

c. Location 3: most distal point at 4mm

d. Location 4: most mesial point at 6mm

e. Location 5: midpoint at 6mm

f. Location 6: most distal point at 6mm

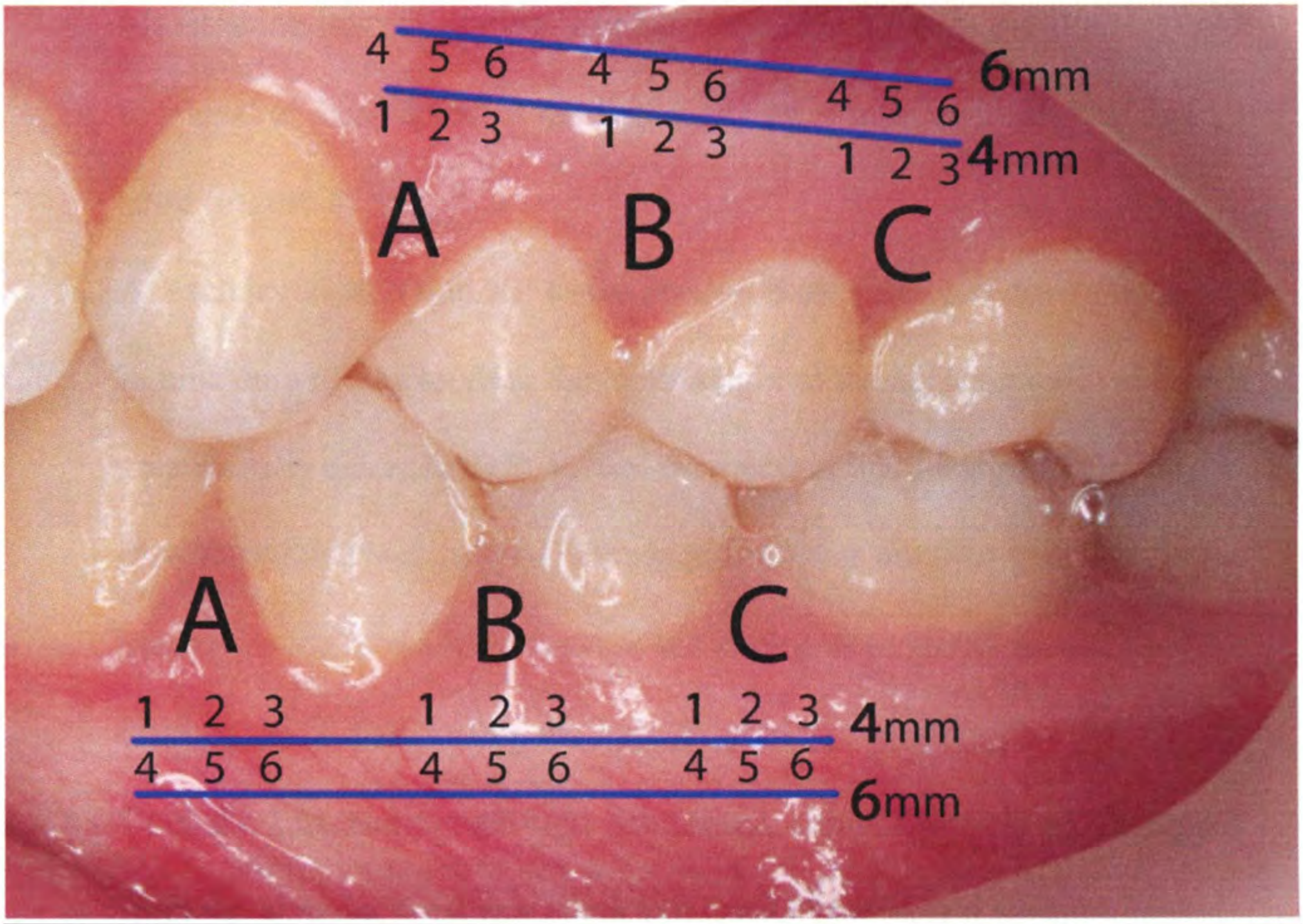


Figure 1. Measurement sites to be evaluated on each subject.

Measurement procedure

1. The image is first aligned from the coronal view, adjusting the image in the sagittal plane so that the bony architecture is symmetrical and a 0° line will pass through the alveolar crest at the same level bilaterally. (Figure 2)
2. The CBCT image is then aligned from the sagittal view by adjusting the axial plane to be parallel with the palatal plane. (Figure 3)
3. The image is maintained in its vertical position and is then rotated so that the CBCT slice runs through the buccal segment containing all locations to be measured.

4. Maintaining this orientation, a linear measurement from the alveolar crest to a level of 4mm apical is measured, and an axial slice is taken at that level (Figure 4)
5. At each location, a line 90° to the cortical bone surface is drawn from the lamina dura of one tooth to the lamina dura of the adjacent tooth at the area visually determined to be the narrowest in that location. This line is then bisected. Three cortical bone measurements are then made 90° to the buccal cortical bone at the level of the lamina dura points as well as at the level of the point bisecting the two. (Figure 5)
6. Once the 3 measurements have been taken, another vertical measurement from the alveolar crest was taken to a level of 6mm, and measurements were repeated at this level.
7. This was repeated for each of the 3 locations in each quadrant.

The demarcation between the 2 bone qualities was identified by visual discrimination between the white contrast of the cortical bone and the gray appearance of the cancellous bone.

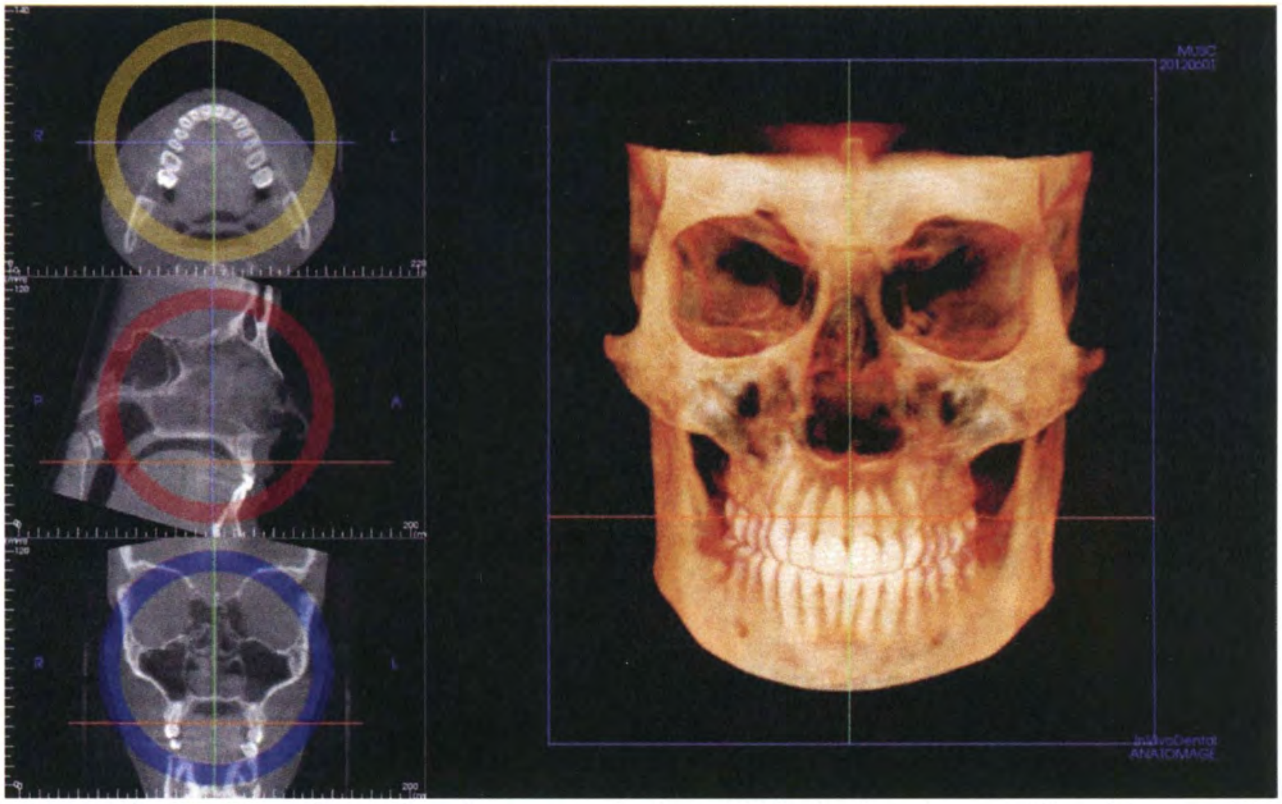


Figure 2. CBCT orientation in coronal view. This is the view utilized in step 1 of the orientation process for each CBCT evaluated for axial alignment along true vertical.

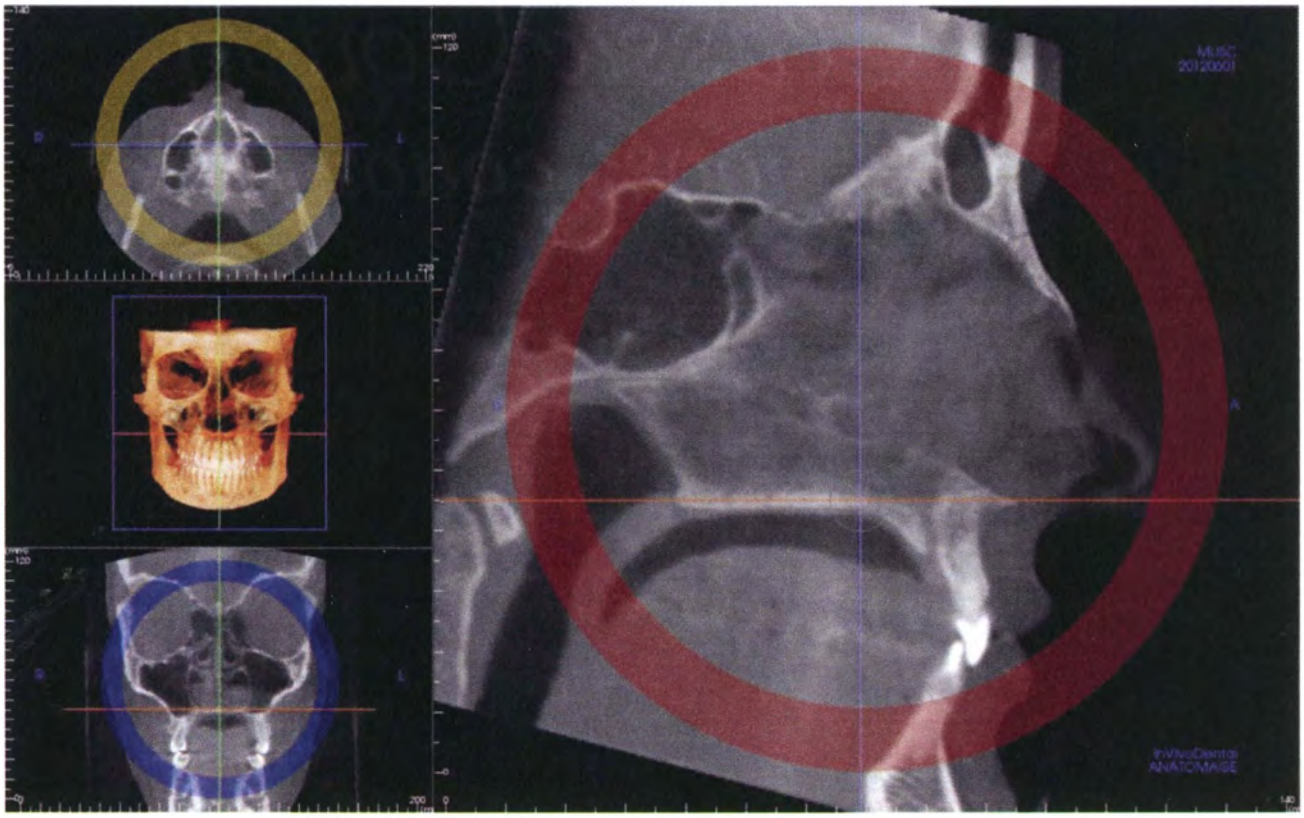


Figure 3. CBCT orientation of the palatal plane. This is the view utilized in step 2 of the orientation process for each CBCT evaluated orienting the palatal plane with a 0° line

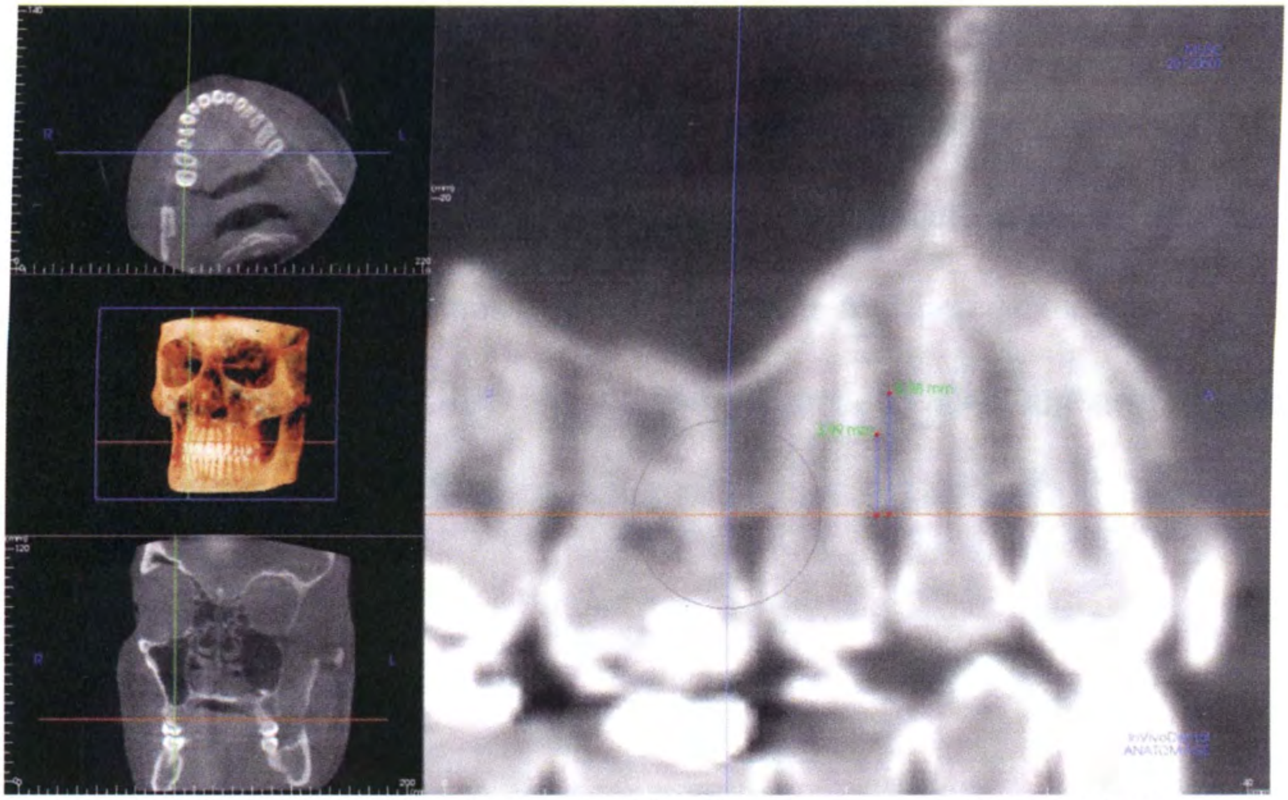


Figure 4. CBCT orientation for vertical level measurement. This is the view utilized in step 4 of the orientation process for each CBCT evaluated marking levels 4 and 6mm from the alveolar crest.

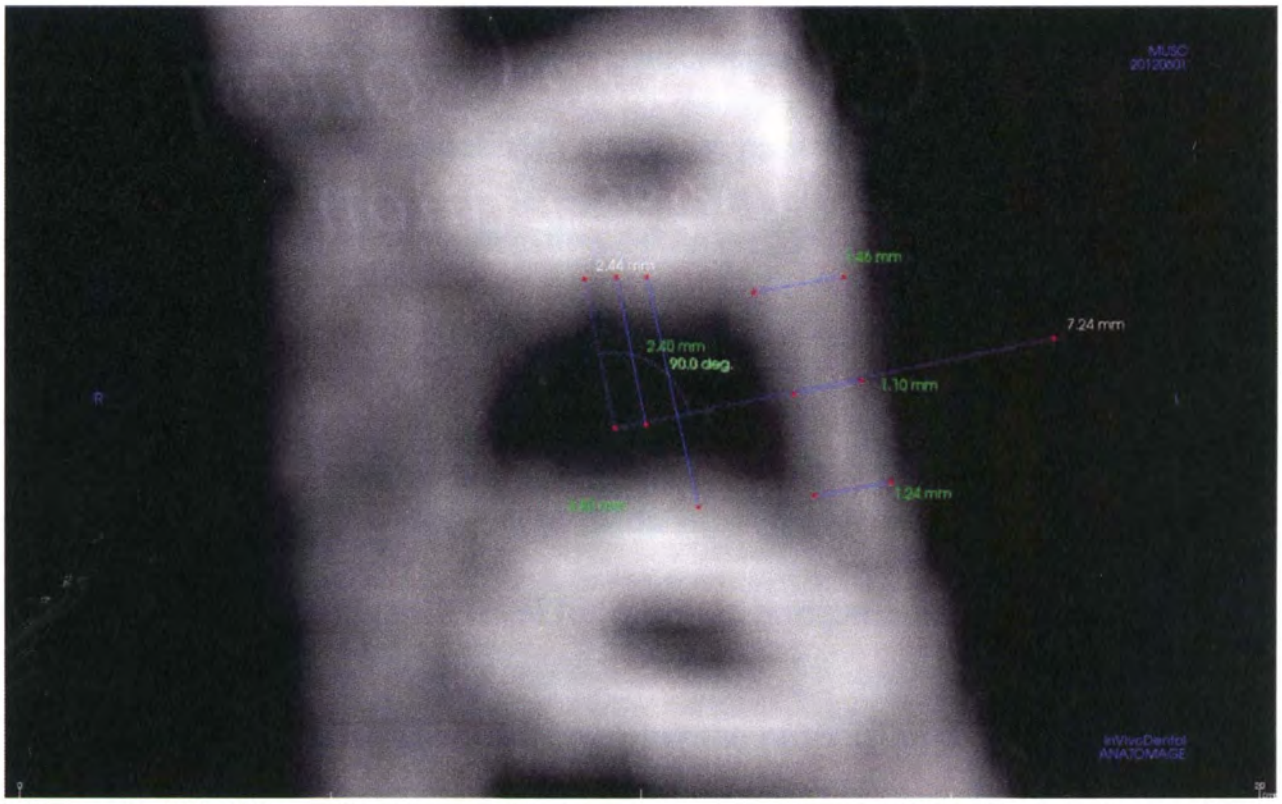


Figure 5. CBCT cortical bone thickness measurements. This is the view utilized in steps 5-7 of the orientation process for each CBCT evaluated showing all of the measurements made at each location.

Prior to collecting data on all subjects, the reliability of measurements collected on each subject was evaluated. The estimated intraclass correlations for across all subject, location, and grid numbers is 0.9218 which suggests excellent agreement between the first and second measures (Note: ICC > 0.8 is considered excellent agreement). The estimated ICC values by jaw, specific tooth location, and grid location ranged between 0.8889 and 0.9545.

Analysis

A total of 50 subjects were included in the study. The cortical bone thickness (in mm) was collected for 36 locations in each participant: 6 measurements at each of three tooth locations in both the mandible and maxilla totaling 18 measurements per arch, 36 measurements per subject , 900 maxillary measurements and 900 mandibular measurements. A linear mixed model with a random patient effect was constructed to account for the correlation between measures taken on the same subject. The maxilla or mandible was considered a main effect but tooth location and grid location were considered to be nested within the jaw. Age and gender were also included as covariates in the model. Pair-wise comparisons were made between variates using a Bonferroni correction to adjust the significance level for multiple comparisons.

An additional analysis included examining the proportion of sites with cortical bone thickness < 1mm (rather than bone thickness in mm) or > 1.5 mm to determine if differences existed between jaws, tooth locations, and grid locations. The model included a random patient effect to account for the correlation between measures taken on the same subject. We considered the proportion of sites with thickness less than 1 mm or greater than 1.5 mm by jaw, by tooth location, by grid number, by tooth location within jaw, by grid number within jaw and by grid number within tooth location within jaw. All analyses were conducted in SAS v. 9.3 (SAS institute, Cary NC).

RESULTS

Cortical Bone Thickness

The mean age in the study population was 35.5 (+/- 16.3) years of age (median = 29, min = 13, max = 79). The study consisted of 28 females and 22 males, and were predominantly white (72%). The multivariable model of cortical bone thickness included age (in years), gender, jaw, tooth location within jaw, grid location within jaw, and an interaction between tooth location and grid location nested within jaw. Neither age nor gender was significant in the final model.

Cortical bone thickness was found with averages ranging from 1.22mm to 1.47mm for the tooth locations studied. (Table 1) Individual grid location means were found to range from as low as 1.13mm between the mandibular canine and first premolar at 4mm to 1.54mm between the mandibular second premolar and first molar at 6mm (Table 2). Overall, the individual measurements were found to range between 0.71mm and 2.29mm. The overall thinnest measurement recorded was in the mandible at location A2, and the overall thickest measurement was recorded in the mandible at location C3 The mean cortical bone thickness was significantly thicker in the mandible relative to the maxilla after controlling for age, gender, tooth location and grid location ($p < 0.001$). Cortical bone thickness in the mandible significantly increased as the tooth location moved posteriorly, however remained constant in the maxilla. Even though the mandibular cortical bone is significantly thicker than the maxillary cortical bone, both the thickest and thinnest mean measurements are in the mandible. (Table 2)

Table 1: Table of mean thickness for different locations in the mandible and maxilla by height at which the measurement was taken

Jaw	Tooth	Mean Thickness (±SD) 4mm	6mm
Mandible	A	1.22 ± 0.21	1.25 ± 0.21
	B	1.35 ± 0.27	1.37 ± 0.24
	C	1.38 ± 0.24	1.47 ± 0.27
Maxilla	A	1.23 ± 0.18	1.29 ± 0.22
	B	1.28 ± 0.23	1.26 ± 0.20
	C	1.25 ± 0.20	1.26 ± 0.19

Table 2: Cortical bone thickness (mean (SD)) by different factors

Height	Grid	Mandible A	Mandible B	Mandible C	Maxilla A	Maxilla B	Maxilla C
4mm	1	1.29 (0.19)	1.40 (0.25)	1.40 (0.23)	1.28 (0.17)	1.33 (0.23)	1.29 (0.21)
	2	1.13 (0.18)*	1.28 (0.24)	1.28 (0.20)	1.15 (0.17)	1.21 (0.23)	1.19 (0.19)
	3	1.25 (0.22)	1.38 (0.31)	1.48 (0.24)	1.26 (0.16)	1.29 (0.21)	1.28 (0.18)
6mm	1	1.30 (0.22)	1.37 (0.24)	1.47 (0.27)	1.35 (0.21)	1.28 (0.20)	1.30 (0.22)
	2	1.16 (0.17)	1.33 (0.22)	1.41 (0.24)	1.23 (0.24)	1.20 (0.19)	1.20 (0.16)
	3	1.29 (0.20)	1.43 (0.25)	1.54 (0.28)*	1.30 (0.21)	1.30 (0.20)	1.29 (0.19)

*Indicates overall thinnest and thickest mean cortical bone thickness measurements. Red indicates thinnest locations in maxilla and mandible, and green indicates thickest locations in maxilla and mandible.

There were no significant differences in cortical bone thickness between different tooth locations in the maxilla (Figure 6). Despite the maxilla showing relatively constant mean thickness as you progress posteriorly, it was observed that there was less variability and more consistent measurements with exterior measurements (1,3,4, and 6) as you move from A to B to C (Figure 7). The opposite was observed in the exterior measurements within the mandible. As you move from A to B to C, the thickness increases, but as well as the variability.

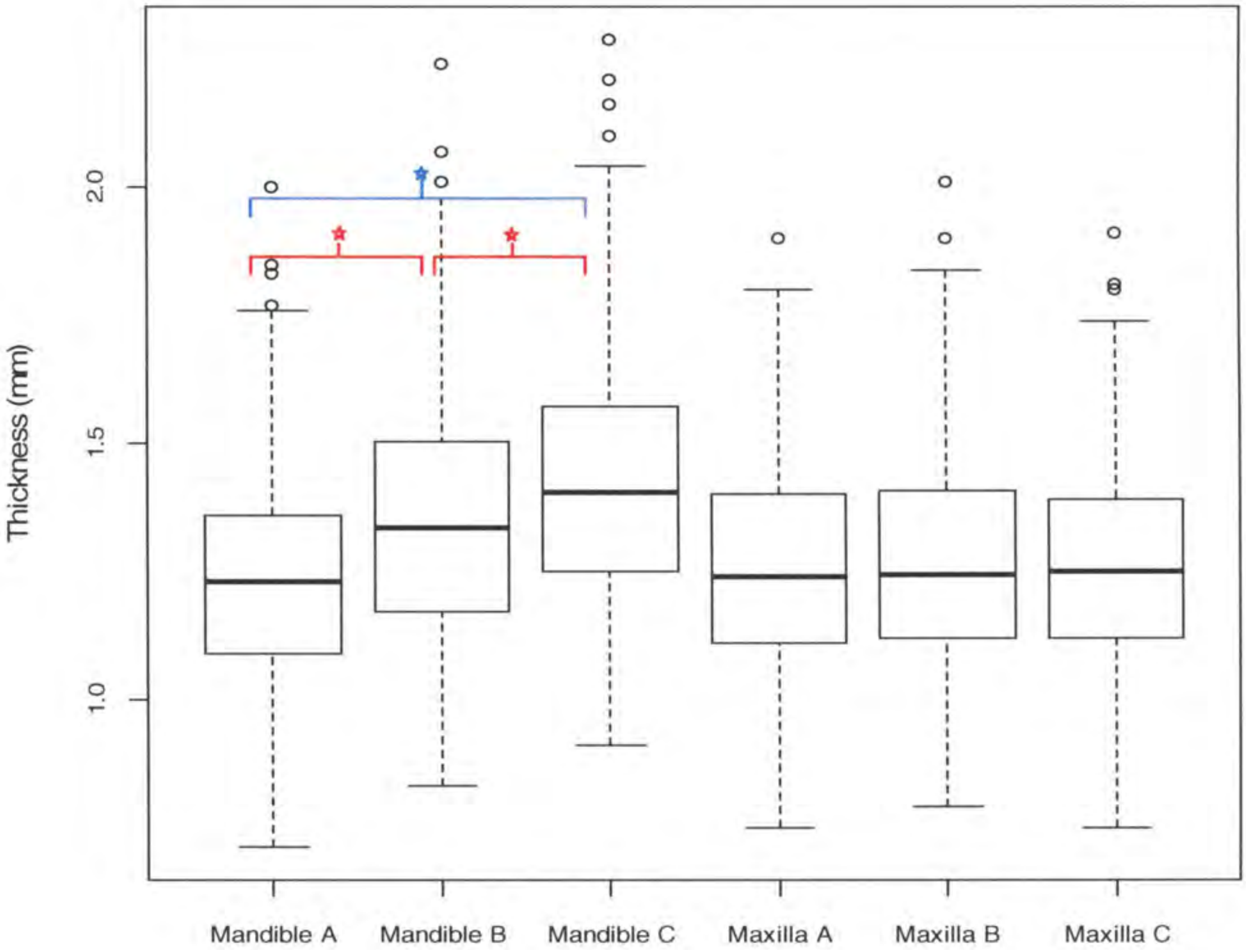


Figure 6. Mean Cortical Bone Thickness for Each Tooth Location by Jaw. (* $p<.0001$) The dark line represents the median, the bottom/top of the box are the 25^{th} and 75^{th} percentiles, the bottom/top bars are the 5^{th} and 95^{th} percentiles, and any points represent "extreme" values.

Figure 7. Mean Cortical Bone Thickness for Each Grid Number by Tooth Location within Jaw.

Center vs. Exterior Measurements

Center grid locations (i.e. locations 2 and 5) are significantly thinner than mesial and distal exterior grid locations 1, 3, 4, and 6 in both the maxilla and mandible. However, there are no significant differences between the different exterior grid locations in either the maxilla or mandible (Figures 8 and 9).

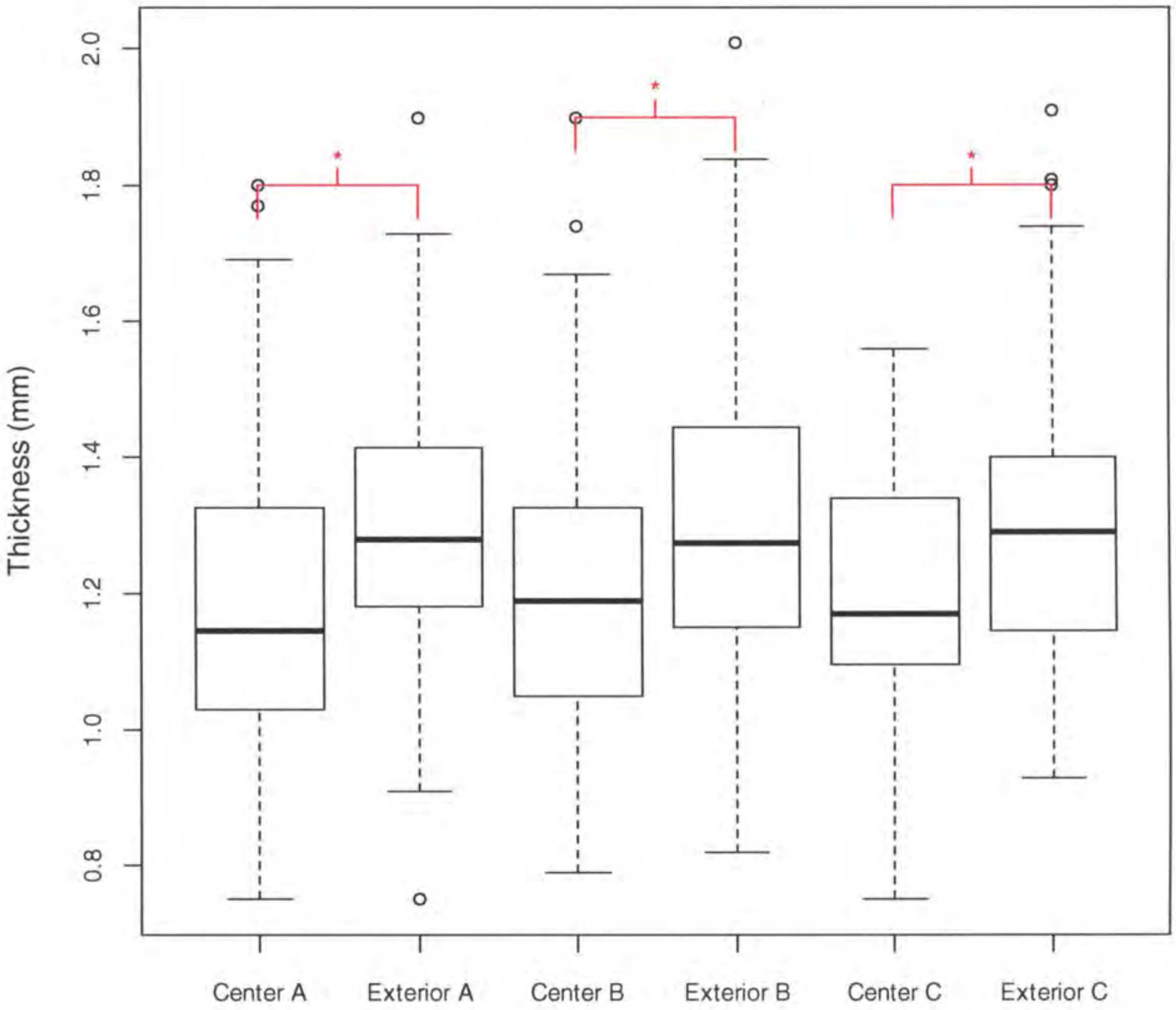


Figure 8. Boxplot of locations A,B, and C within the Maxilla by center grid (2 & 5) versus exterior grid (1, 3, 4, & 6). (*p<.0001) None of the comparisons within center between location or within exterior but between location were statistically significant. The dark line represents the median, the bottom/top of the box are the 25th and 75th percentiles, the bottom/top bars are the 5th and 95th percentiles, and any points represent "extreme" values.

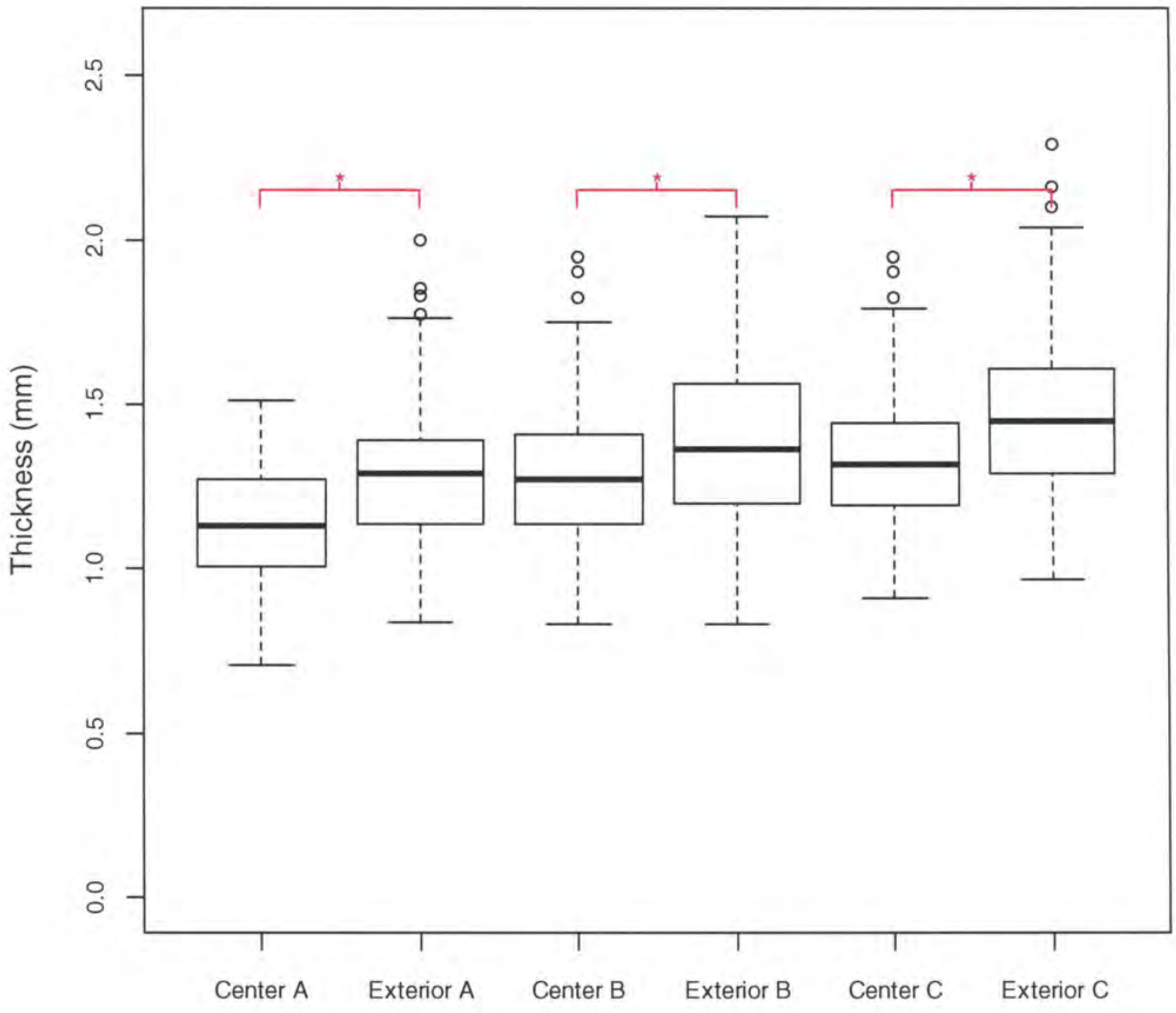


Figure 9. Boxplot of Location (ABC) within the Mandible by center grid (2 & 5) versus exterior grid (1, 3, 4, & 6). (*p<0.001) The dark line represents the median, the bottom/top of the box are the 25th and 75th percentiles, the bottom/top bars are the 5th and 95th percentiles, and any points represent "extreme" values.

The midpoint between 2 adjacent teeth returned cortical bone thickness levels thinner than the cortical bone directly adjacent to roots regardless of tooth location or jaw. This was particularly true for location 2 (midpoint at 4mm) relative to all exterior grid locations.

Regions where bone thickness is <1mm

There was no significant difference in the proportion of sites with bone thickness < 1mm in the mandible vs. the maxilla (Table 3). Across jaws, tooth location A (Canine to First Premolar) had a significantly greater proportion of teeth with thickness < 1mm relative to site C ($p = 0.007$). Across both jaw and tooth location, grid 2 had a significantly greater proportion of sites with bone thickness < 1mm relative to all other sites. (Figure 10) This was not isolated as grid 2 had a significantly greater proportion of sites with bone thickness < 1mm relative to sites 1 and 6 across both jaws. Within the Maxilla, there was no significant difference in the proportion of sites with thickness <1 mm between tooth locations A, B, or C. However, within the mandible, tooth location A had significantly more sites with thickness < 1mm relative to tooth locations B and C ($p = 0.003$ and < 0.001 respectively). There were two sites with the greatest number of thickness measurements less than 1mm: (1) Mandible A2 had 10 of 50 (20%) sites with thicknesses < 1mm and (2) Mandible A5 also had 10 of 50 (20%) sites with thicknesses <1mm (Figure 11). The next highest proportion of sites <1mm were in the maxilla at grid 2 in location A as well as B (18% respectively).

Within the maxilla, grid 2 had significantly more sites with thickness < 1mm relative to sites 1, 3, 4, and 6 ($p = 0.002, 0.001, 0.002, 0.001$ respectively) while grid 5 had significantly more sites relative to sites 3 and 6 ($p = 0.018$ and 0.018 respectively). Within the mandible, grid 2 had significantly more sites with thickness < 1mm relative to sites 1, 4, 5, and 6 (p = 0.001, 0.009, 0.049, 0.001 respectively) while site 5 was only significantly different from site 1 (p = 0.033).

Table 3: Proportion of sites with cortical bone thickness < 1mm by jaw

Factor	Level	Proportion	% Thickness < 1mm
Jaw	Mandible	60/900	6.67%
	Maxilla	70/900	7.78%

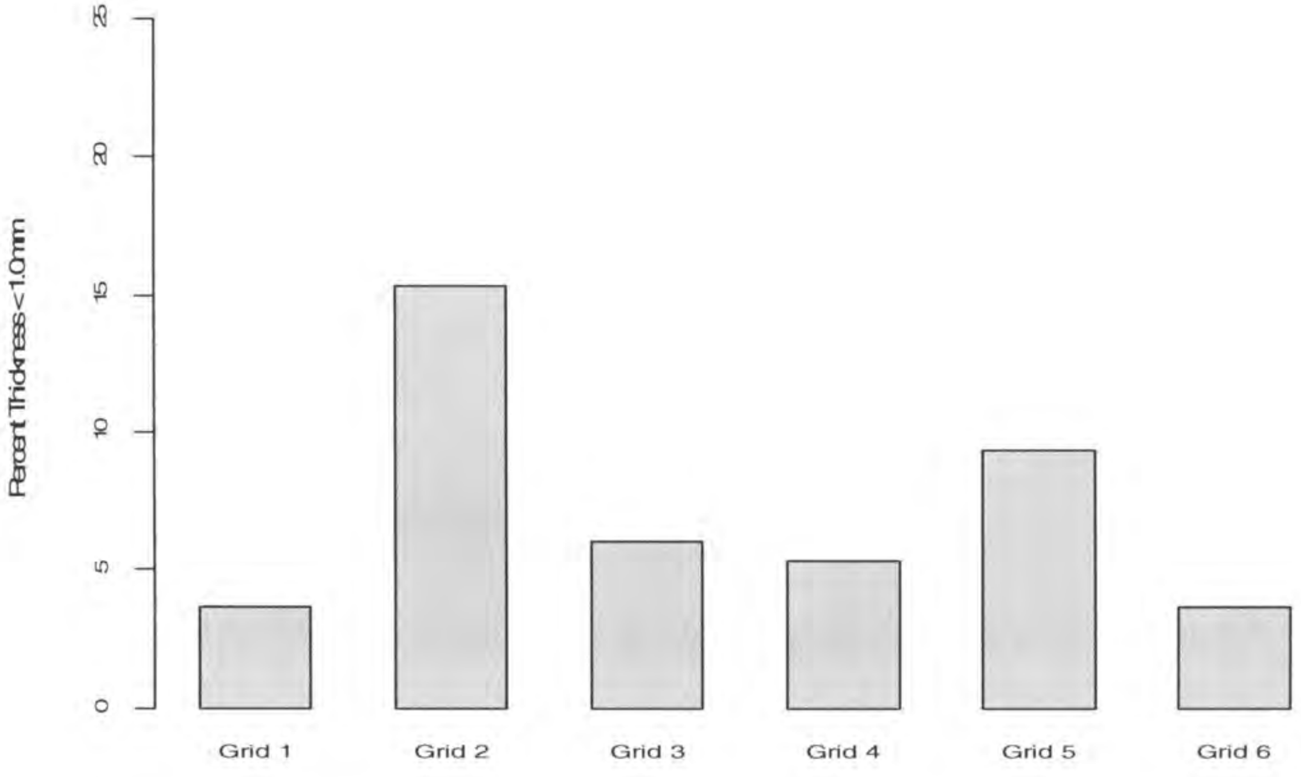


Figure 10. Bar graph showing percentage of sites with thickness <1mm by grid number

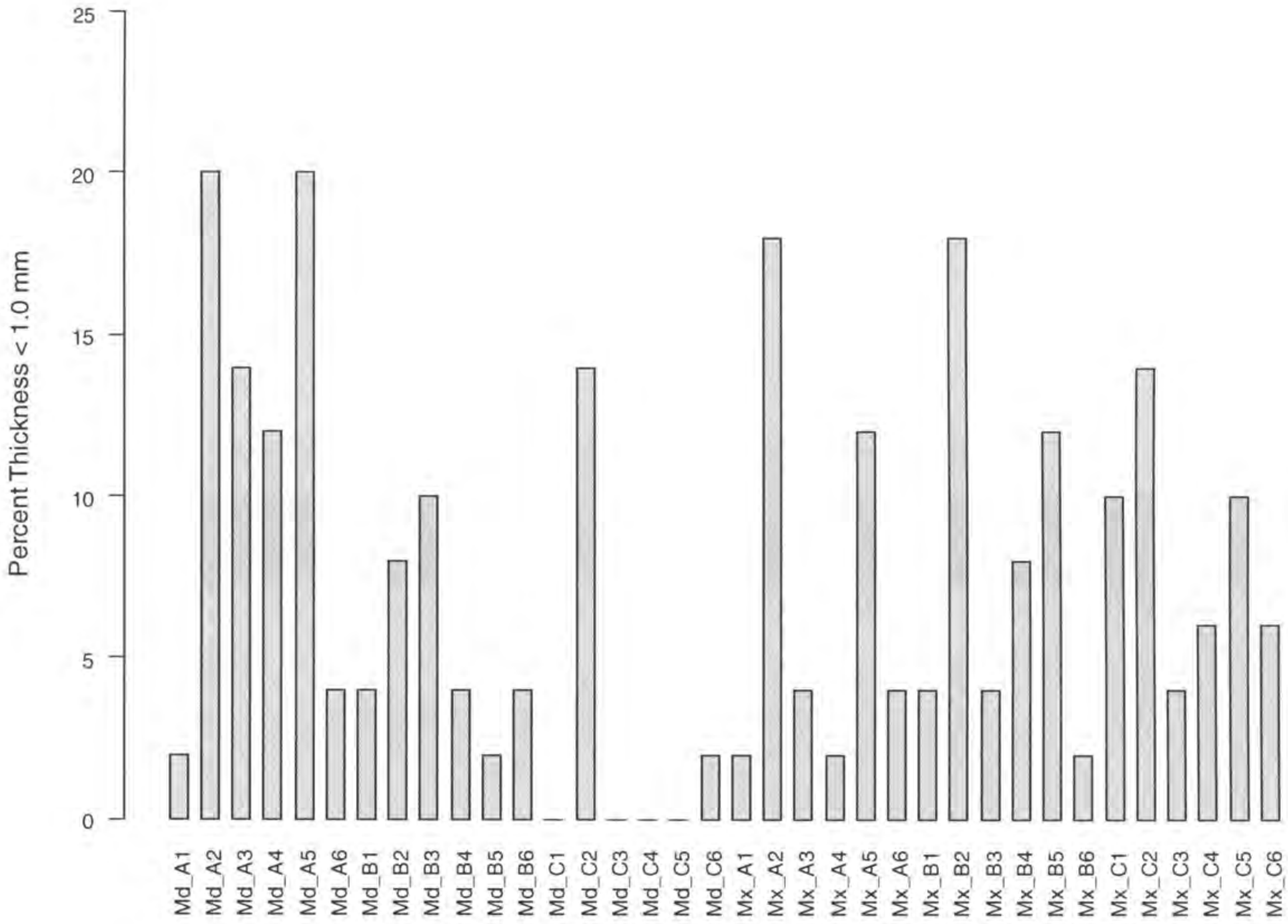


Figure 11: percentage of sites with measurements less than 1mm in all measurement locations

Regions where bone thickness is >1.5mm

The mandible had a significant greater proportion of sites with cortical bone thickness >1.5mm (22.4%) relative to the maxilla (11.4%) ($p < 0.001$) (Table 4). Across both jaws, tooth location A had a significantly smaller proportion of teeth with thickness >1.5 mm relative to sites B and C ($p < 0.001$ for both). When isolated to each jaw, location A had a significantly smaller proportion of sites >1.5 than B and C for the mandible, however there are no significant differences between locations A, B, and C in the maxilla. Across both jaws and tooth locations, grid 2 and 5 both had a significantly smaller proportion of sites with bone thickness > 1.5mm relative to sites 1, 3, 4, and 6 (Figure 12).

Table 4: Proportion of sites with measurments >1.5mm and <1.5mm

Factor	Level	Proportion	% Thickness >1.5mm
Jaw	Mandible	202/900	22.4%
	Maxilla	100/900	11.1%

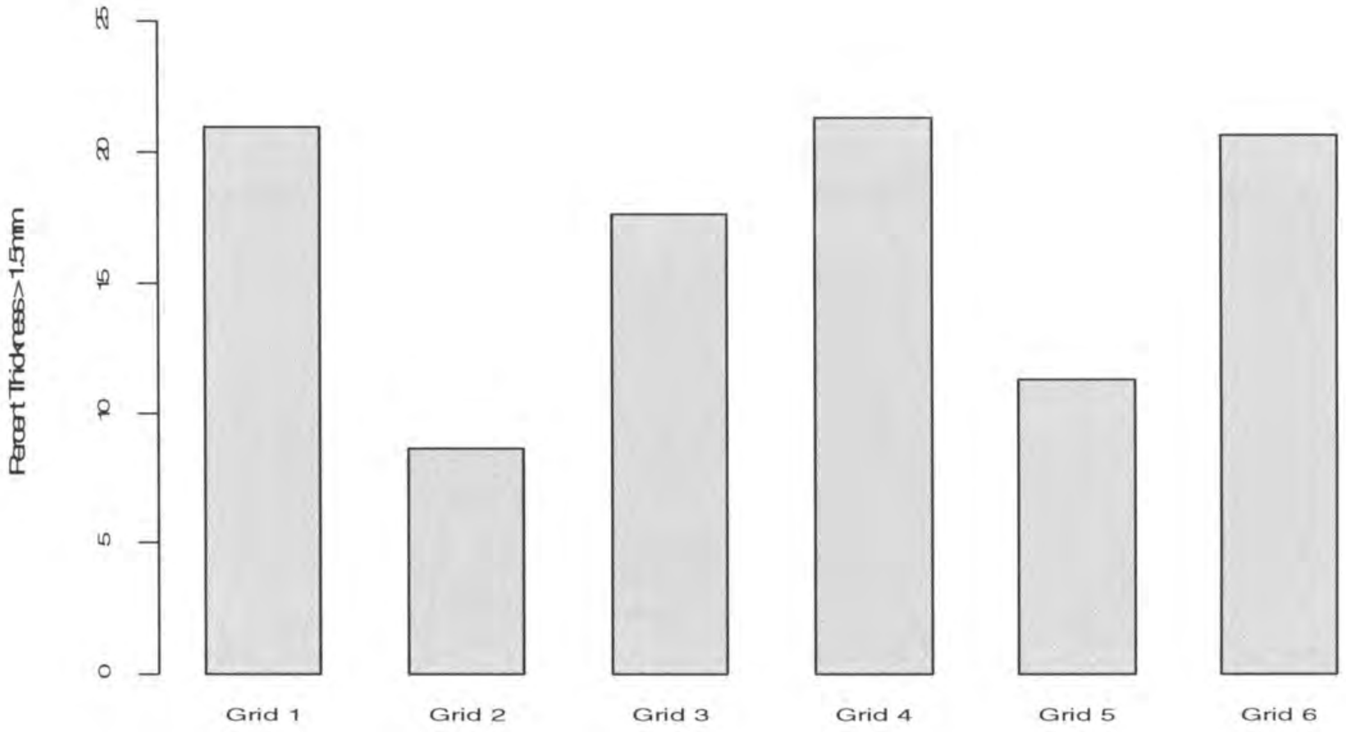


Figure 12. Percentage of sites with thickness >1.5mm by grid number.

The 2 sites in the study that are most posteriorly located within the mandible are also the 2 sites that reported the largest percent of their measurements being >1.5mm. Site C6 recorded measurements > 1.5mm close to 50% of the time, and C3 recorded measurements >1.5mm 40% of the time (Figure 13). The site which had previously recorded the largest proportion of measurements <1mm (Mandible A2) was also the site that recorded the lowest percentage of measurements >1.5mm.

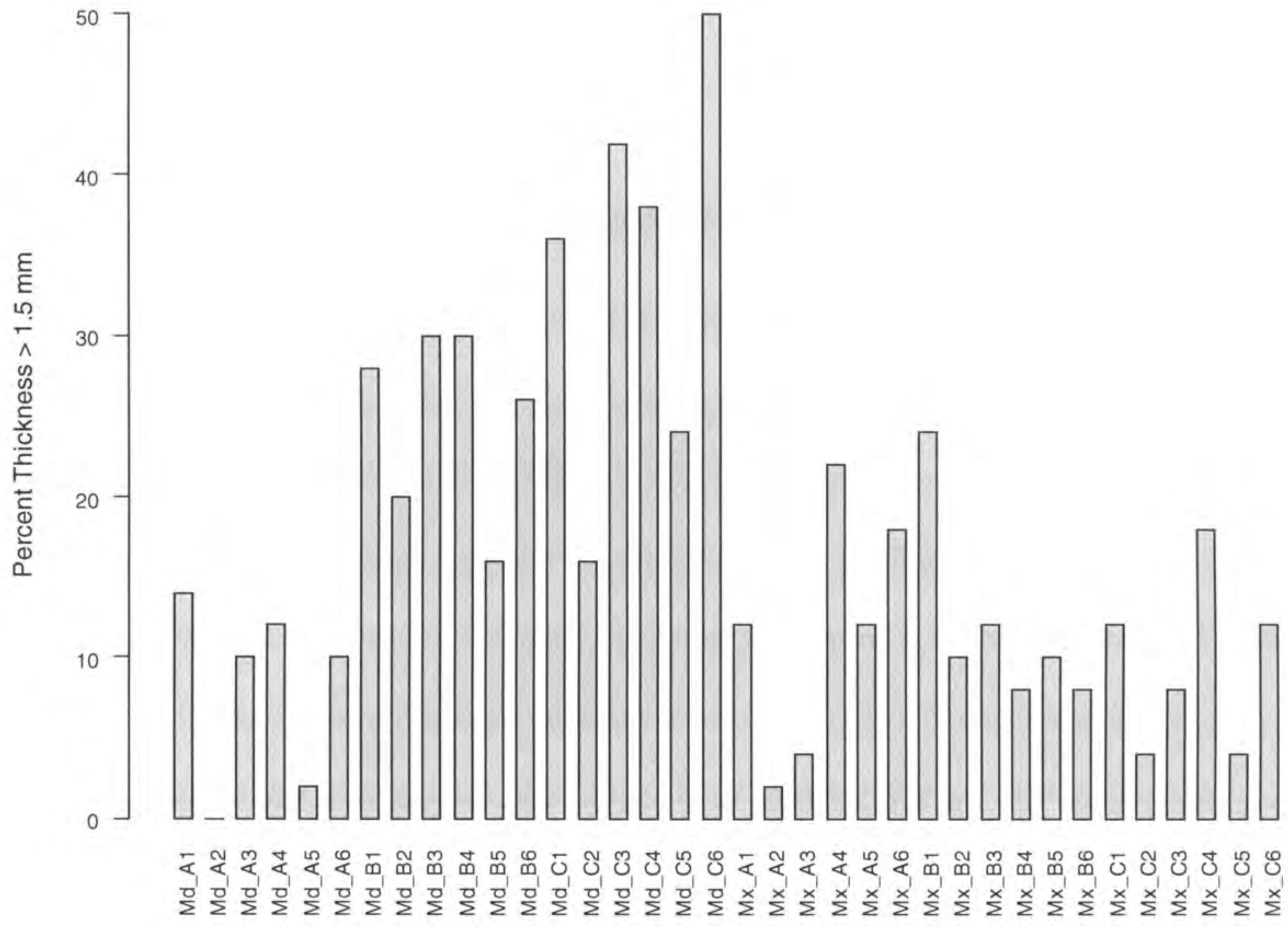


Figure 13. Percentage of sites with measurements greater than 1.5mm by jaw, location, and grid number.

DISCUSSION

The aim of the study was to identify horizontal buccal cortical bone patterns in each location interproximally in the buccal segments of the maxilla and mandible. The null hypothesis was rejected, and there was in fact a significant pattern of cortical bone thinning as you approach the point bisecting two teeth. In all locations, in all levels, in both jaws, the bone was significantly thicker as you approach the roots of teeth. The areas not under the stress of function (midway between two teeth), or under less stress from function, did not have as thick of a cortical bone covering. We can also support the opposite finding that the bone surrounding roots of teeth in function, especially as we approach the posterior will be supported by thicker cortical bone.

Given the previously discussed knowledge of cortical bone becoming thicker as you move apically, it was verified that the thinnest sites were the most anterior sites (A), at the 4mm level, and at the point bisecting the canine and first premolar (Site A2). And at the other end of the spectrum, the thickest cortical bone measurements were found as you approximate the root of the first molar and at the 6mm level (C6).

Because most practitioners aim directly between teeth and do not attempt to aim their MSI's mesial or distal and risk hitting the roots, they are most likely placing them in the area of thinnest bone in that region. It is often recommended that due to small interradicular spaces, the safest placement strategy is to place every MSI directly in the middle of the interproximal site.[6] Even with the knowledge of the cortical bone becoming thinner at the midpoint, it should not be alarming. The commonly used sites that were measured in this study reported mostly acceptable cortical bone thickness measurements at even the thinnest areas. It was shown in the results of the current study that less than 14% of all the sites measured reported measurements below 1mm. (Table 3) This is particularly true of the <1mm measurements that are found more posteriorly or apically within the studied areas. These thinnest sites were noted at the canine-premolar location (A), and more commonly found in the mandible than the maxilla. (Figure 11)

It was shown that less than 17% of all measurements were greater than 1.5mm, and less than 14% of all measurements were less than 1mm. This indicates that close to 70% of all the locations measured in this study are suitable for placing MSI's without pilot hole preparation. This is based upon previous guidelines for cortical bone thickness requirements.[13]

Not surprisingly, as was found with most of the other studies, no age or sex significance could be drawn from our results. It is possible that age and sex related differences in bone are more related to bone quality (i.e. density) and not necessarily quantity. An interesting study would be to include Hounsfield measurements of cortical bone in MSI locations from CBCT's while comparing age and sex. This might be the only way to support studies showing success rates being affected by age while cortical bone thickness not being affected.

Because many of the measurements were made in areas previously studied, this study was able to confirm much of what has already been reported. It was found that all the areas studied were appropriate for MSI placement based upon previous guidelines for cortical bone thickness[13, 77]. In the maxillary arch, bone is relatively consistent with the most ideal level for placement being at 6mm apical to the alveolar crest. There was also confirmation of previously reported data showing that mandibular cortical bone is thicker than maxillary cortical bone, and that there is a pattern increasing cortical bone thickness when moving from anterior to posterior. Many studies have suggested that cortical bone thickness increases from anterior to posterior in both the maxilla and mandible[13, 77], however the patient population in this study only displayed this pattern in the mandible. Similar findings have been reported in the literature showing mandibular measurements getting thicker apically and posteriorly, whereas the maxilla remains relatively constant. [6, 11, 80] The studies referenced in this paper discussing growth pattern, cortical bone thickness, and the way that function affects bony modeling have already explained why this occurs. If a posterior tooth has more biting force than an anterior tooth, then it would make sense that the more posterior that tooth is located, the thicker the bone would be around the roots of that tooth. It becomes so thick in the mandible that MSI placement becomes more likely to result in failure if proper placement protocols do not address this.

A common recommended first choice for placement sites are areas mesial to the first molar. This is due to ideal cortical bone thickness as well as increased interadicular space.[13, 26, 28, 29] The average thickness in location C (adjacent to the first molar) was 1.26mm which was not significantly better than the rest of the locations studied for MSI placement. The only advantage this location has is the ability to have more room to place the MSI as you approach the 6mm mark and roots diverge.

One interesting finding was the relationship between the variability of thicknesses at different locations between the maxilla and mandible. As shown in the results of the study, the average maxillary bone thicknesses are not significantly different, however the variability in the cortical bone thickness of the exterior locations decreases as you move posteriorly. Tooth location A, while it reports an average cortical bone thickness level of 1.26, it has a much larger range with some measurements being below 1mm and some being closer to 1.5mm. As you approach location C, the bone is more consistently reported as being close to 1.26mm. In the mandible though, there is a clear progression of bone getting thicker as you move posteriorly, without a change in variability.

Because there were so few locations with measurements below 1mm, it should be reasonably acceptable to place an MSI in any of the more anterior locations with a 90° insertion angle and at either the 4 or 6mm level whether you are directly in-between 2 teeth, or off to one side. Because of the narrow interradicular space, most clinicians will probably not have a choice, and be forced to place their MSI directly between the 2 teeth, especially when they are at the 4mm level (roots diverge as you move apically providing more distance to vary placement). If there was one variation in placement planning, it may be to place your MSI at a slight angle in the direction of force application when placing in location A (between the canine and first premolar), at a 4mm level (5mm from the CEJ) in the mandible. This will maximize the amount of cortical bone that the MSI passes through in an area with the least cortical bone thickness. This same placement protocol could be applied to the maxilla, however there were fewer locations with less than 1mm cortical bone thickness in the maxilla than the mandible.

Another application of our new knowledge lies at the other end of the spectrum related to cortical bone that is thicker than desired. Baumgaertel suggested drilling pilot holes once you have more than 1.5mm cortical bone thickness. As you move posteriorly and apically you have more availability of mesio-distal placement options. The thickest area reported in this study is at the 6mm level in location C. Given this study's finding that the mean average in the mandible at point C is 1.43 +/- .26mm and that is the thinnest amount expected in that location regardless of angle of insertion, the clinician is in danger of having cortical bone that is too thick for successful MSI placement. Beyond this amount of thickness, if insertion angle is changed from 90°, or if placement is too close to a root surface, it may introduce too much torque and heat during placement. This increased amount of contact with cortical bone can ultimately result in MSI failure. If it is accepted that bone in these areas is too thick to place with long term success, then an attempt to maintain a 90° insertion must be made, and the clinician should consider Baumgaertel's suggestion to place a pilot hole.

Pilot holes have been argued for and against by many individuals in orthodontics. The use of a pilot hole may be the most effective way to maximize your success in an area where there is a high likelihood of thick cortical bone, but there it adds a step, involves tissue punching, and drilling through bone which many people ultimately consider a surgical procedure. It has been advocated by many that in order to not have to adhere to surgical procedure guidelines, the orthodontist must avoid any drilling through bone or creation of any mucoperiosteal flaps.[81] In the end, it may just be easier and more convenient to choose a new location for placement.

CONCLUSIONS

Coupling previous knowledge with our latest findings, we have created a new set of strategies to aid in placement of MSI's in buccal bone. Placement must first begin with regional selection which is based upon anchorage needs and mechanics to be employed.

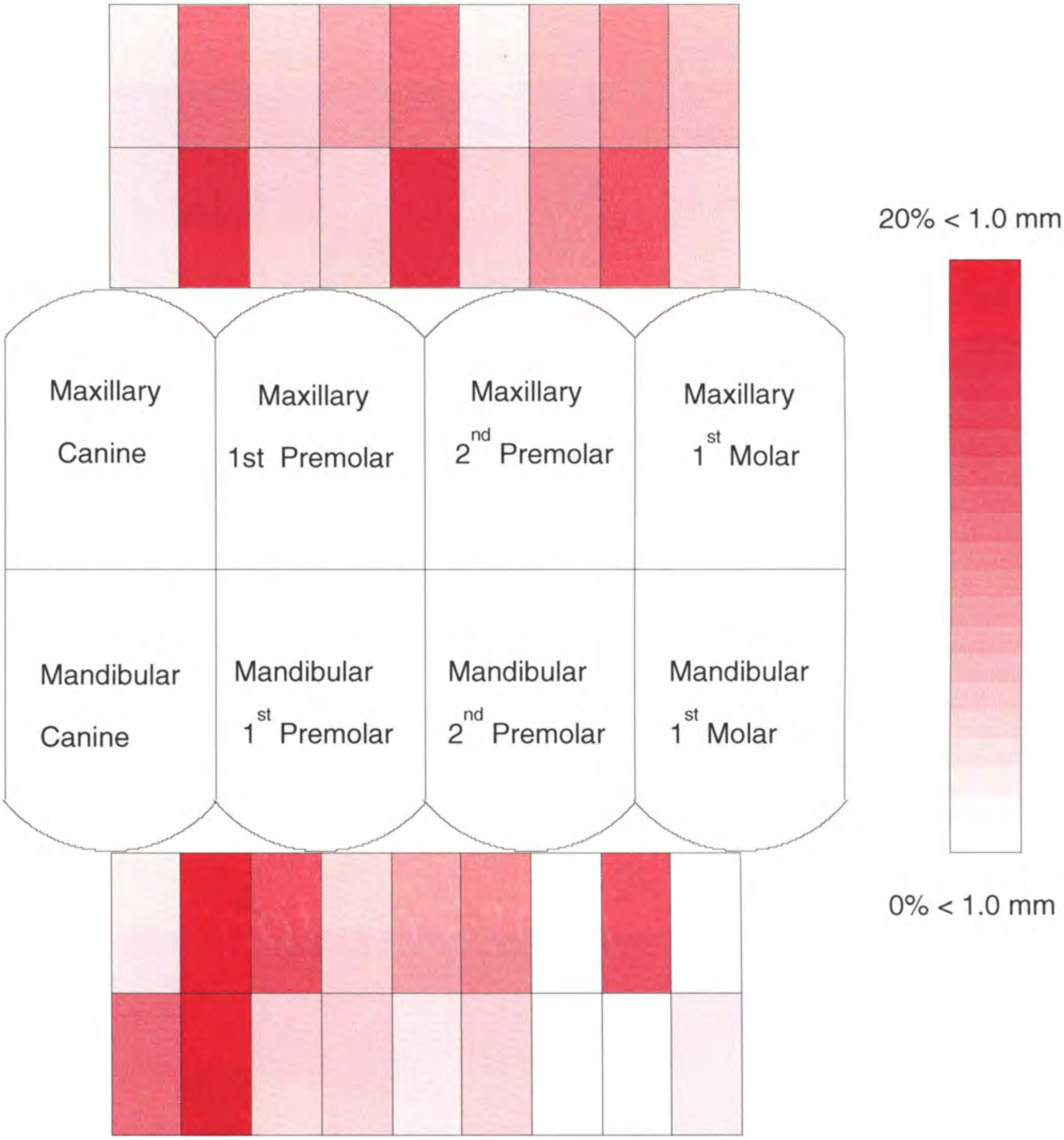
For the maxillary arch:

- Placement between the canine and first premolar
  - Place at midpoint between the two teeth at a 6mm level from the alveolar crest. If tissue mobility will not allow placement at 6mm, then placement must be made as close to it as possible. In order to maximize cortical bone thickness penetration, angle the MSI slightly apically.
- Placement between the first and second premolars
  - Place at the midpoint between the 2 teeth as close to 6mm from the alveolar crest as tissue will allow. Place with an insertion angle of 90°.
- Placement between the second premolar and first molar
  - Place as close to 6mm from the alveolar crest as tissue will allow and at an insertion angle of 90°. Mesio-distal placement is dictated by mechanics required. (ex: for distalization place closer to the molar by 1.5mm)

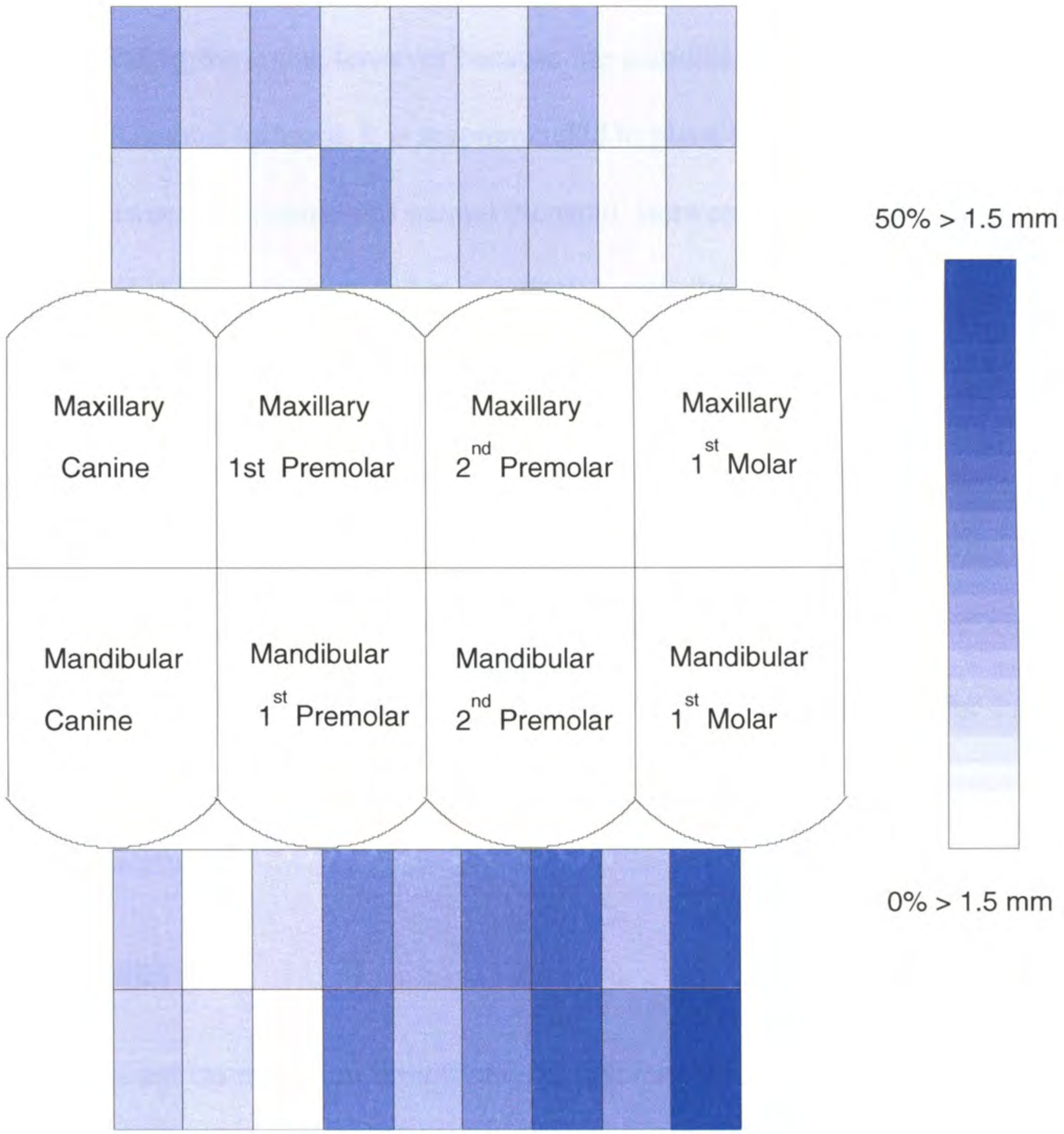
For the mandibular arch:

- Placement between canine and first premolar

    - Place at midpoint between the two teeth at a 4mm level from the alveolar crest or as apical as tissue will allow. In order to maximize cortical bone thickness penetration, angle the MSI slightly apically.
- Placement between first and second premolars
    - Place at the midpoint between the 2 teeth as apical as tissue will allow. Place with an insertion angle of 90°
- Placement between second premolar and first molar
    - Place at the midpoint between the 2 teeth, and at a level of 4 mm from the alveolar crest with an insertion angle of 90°. Mesio-distal variations in placement are not recommended.



Figures 14: Alternative way to visualize the number of sites <1mm at each specific location… The plots below show a general layout of the mouth showing the teeth in the mandible and maxilla. The grid containing the 18 blocks represents the 6 grid locations between each of the teeth (6 grid numbers * 3 spaces between teeth = 18). The darker the color, the greater the percentage of sites in the study with thickness < 1.0 mm



Figures 15: Alternative way to visualize the number of sites >1.5mm at each specific location... The plots below show a general layout of the mouth showing the teeth in the mandible and maxilla. The grid containing the 18 blocks represents the 6 grid locations between each of the teeth (6 grid numbers * 3 spaces between teeth = 18). The darker the color, the greater the percentage of sites in the study with thickness >1.5mm

Purposeful divergence of roots is acceptable and likely advantageous the more anterior your site is located. It is not recommended to go higher than 6mm in the maxilla due to risk of perforating the sinus, however because the mandible has no anatomic risks until the level of the mental foramen, it is recommended to place the MSI as apical as the tissue will allow between the canine and second bicuspid. Between the second bicuspid and the first molar, it is not recommended to aim further apically than 4mm due to the cortical bone thickness increases that are associated.

It is recommended to monitor torque levels while placing not only to avoid damage to bone, but to identify possible contact with a root, (by dramatic increase in torque) penetration of cortical bone on the other side of the alveolus, and as an indication of when the collar of the MSI has been fully seated onto the bone. When limited options are available and mechanics will allow, other sites such as the palate have been shown to be very ideal for placement.

Limitations of the study

This study is not exempt from limitations. The patient population in this study, although had a good distribution of age and sex, was skewed toward Caucasian populations and may not be an accurate guide for all ethnicities.

Future areas of research

It would be beneficial to see how cortical bone changes in edentulous areas and how variable the bony pattern is in larger spans and in different regions of the maxilla and mandible. It would also be interesting to see age/sex/ethnicity variations in CBCT measurements whether it is cortical thickness or density by Hounsfield units. By controlling for study population and ensuring an even distribution, it could shed light on a highly debated topic in bone studies.

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