Effect Of High-Frequency Vibration on Periodontal Tooth Mobility

by

Sameer Bajaj

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

Medical Sciences-Periodontology

University of Alberta

Abstract

Periodontal disease also known as periodontitis is the second most common cause of tooth loss after dental caries. Almost close to half of the population of the world suffers from various forms (mild, moderate, or severe) of the periodontal disease. The disease is prevalent in mankind because of twofold reasons; inadequate diagnosis and inadequate treatment. The sequela of periodontal disease results in progressive loss of clinical attachment (supporting bone structure) around the teeth. One of the classic self-reported symptoms of periodontitis by the patients is loosening of the teeth which is termed in dental field as tooth mobility. The loss of supporting bone around the tooth makes the tooth mobile, sequentially leading to the tooth loss. If the periodontal disease is diagnosed timely and adequate efforts are made to prevent further loss of attachment, tooth loss can be prevented.

Traditional and time-tested methods of treating periodontal disease includes non-surgical (scaling and root planning) and surgical intervention. It is said that once a periodontal patient, always a periodontal patient and therefore these patients need to be on supportive periodontal therapy for a long time to save their teeth. Along with these tried and tested approaches clinicians, keep on exploring novel adjunct techniques to improve outcomes of periodontal patients.

Bio-stimulation of hard and soft tissue to enhance or accelerate healing is an exciting area of inquiry, with the potential to have broad clinical application in periodontics. High-frequency vibration (HFV) is routinely used as an adjunct in the field of orthodontics to accelerate the movement of the teeth and reduce treatment times. Their modality is based on bio-stimulation of the inflamed periodontium (inflamed due to orthodontic forces). We hypothesized to use HFV in

well maintained periodontal patients (non-inflamed periodontium) possibly stimulating bone cells to form bone around the teeth thus improving clinical tooth mobility.

A total of 17 patients were recruited for this pilot randomized clinical trial, first study of its kind in the field of periodontology to study the effects of HFV on the periodontium in a clinical graduate program setting. Research participants were randomly allocated to the test and the control group. The test group participants received HFV through the PTech device for five minutes per night for 12 weeks. The measurable outcomes were changes in clinical tooth mobility as shown by the Periotest value (PTV) and any change in bone mineral density (BMD) as measured in Hounsfield units (HU) deduced from the CBCT. The unit of measurement was the tooth and measurements (both PTV and HU) at the same tooth were made at the baseline examination and a subsequent examination at three months by the same provider.

The sample consisted of 416 teeth (all the teeth in 17 patients) on which measurements were done at the baseline and at three months. A one-way repeated measures ANOVA for dependent samples was performed for statistical analyses. Two separate analysis were carried out; one for the entire data set and the other for the target teeth (mobile teeth) only. At the end of the study when considering target teeth (114 mobile teeth) we concluded that there was no evidence of change in the clinical tooth mobility as shown by the Periotest value (PTV) or by Miller's method. Similarly, there was no evidence of change in the BMD as determined by HU. Future studies on a larger scale and longer duration are needed to validate and extrapolate the results of this pilot study.

Preface

This thesis is the original work of Sameer Bajaj. This research project was approved by the University of Alberta's Health Research Ethics Board - Health Panel under the name "Effect of High-Frequency Vibration on Periodontal Tooth Mobility; No: Pro00102774" (Appendix A).

My role included working with the Principal Investigator to develop the research protocol, applying and receiving ethics approval, collecting data on patients, conducting a literature review, analyzing data, and writing the manuscript. The Principal Investigator, Dr. Douglas Dederich, was my supervisor, and Dr. Monica Gibson and Dr. Tarek El-Baily were my committee members.

The devices used for the test group versus control group were provided by the PTech (Periotech Solutions LLC) at no cost to the patients and the Graduate Periodontology program.

No part of this thesis has been previously published.

Acknowledgments

I would first like to thank my supervisor, Dr. Douglas Dederich, for his constant support, guidance, and motivation. The door to Dr. Dederich's office was always open whenever I ran into trouble or had a question about my research project. It would not have been possible for me to complete this work without his constant support and generosity.

Next, I would like to thank my supervisory committee — Drs. Monica Gibson and Tarek El-Baily for their support and direction in my research. A special thanks to Dr. Giseon Heo for her help and immense support in statistical analysis of my research data. I would also like to thank the support staff in my Graduate Periodontology department, including; Amy, Shirlene, Tammy, Tina, Kim, Sandra, Carla, Ashley and Melanie who helped me to coordinate patients and collect research data.

Lastly, I would like to express my gratitude to my parents and most importantly to my younger sister, Ms. Sonal Bajaj, for providing me with unfailing support and continuous encouragement throughout the years of this program. A big thank you to all my co-residents in my periodontology program for always supporting and motivating me. This accomplishment would not have been possible without them. Thank you.

Sameer Bajaj

Table of Contents

List of Figures

List of Tables

List of Acronyms

ANOVA	Analysis of Variance
ALP	Alkaline Phosphatase
ASA	American Society of Anesthesiology
BMD	Bone Mineral Density
CAL	Clinical Attachment Loss
CBCT	Cone Beam Computed Tomography
CT	Computerized Tomography
DICOM	Digital Imaging and Communications in Medicine
GS	Graduate Student
HFV	High-Frequency Vibration
HU	Hounsfield units
HREB	Human Research Ethics Board
LMHF	Low Magnitude High Frequency
LMHFV	Low Magnitude High Frequency Vibration
mCT	Medical-grade Computed Tomographic Radiography
MDCT	Multidetector Computed Tomography
NEVD	Non-Contact Electromagnetic Vibration Device
NHANES	National Health and Nutrition Examination Survey
OCN	Osteocalcin
OPG	Osteoprotegerin
PAOO	Periodontally Assisted Osteogenic Orthodontics

PDL	Periodontal Ligament
PDLSCs	Periodontal Ligament Stem Cells
PI	Principal Investigator
PTech	PerioTech LLC Vibration device
PTV	Periotest Value
RCT	Randomized Clinical Trial
RDA	Registered Dental Assistant
RANKL	Receptor Activator of Nuclear factor-κB Ligand
SOST	Sost gene
SPT	Supportive Periodontal Therapy
TFO	Trauma From Occlusion
TMJ	Temporomandibular Joints
TC	Treatment Coordinator

1. Introduction

This chapter reviews periodontal disease and its sequela leading to bone loss and mobile teeth. It explores the relevant literature on the effects of vibration (both high-frequency and low-frequency) on tooth mobility. The chapter also highlights the current available methods used to assess tooth mobility, their clinical reliability, and quantification. Lastly, the chapter describes in depth the study's objectives and research question.

1.1 Periodontal Disease (Periodontitis)

Periodontitis is a chronic multifactorial inflammatory disease characterized by progressive destruction of tooth supporting apparatus (Tonetti, Greenwell, & Kornman, 2018). The destruction is associated with the presence of microbial dysbiotic biofilms, which cause host-mediated inflammation in a susceptible host. The pathognomonic feature is loss of periodontal attachment, demonstrated clinically as periodontal pocketing and gingival bleeding, leading to clinical attachment loss (CAL) and radiographically measured alveolar bone loss (Papapanou, et al., 2018). Periodontitis is a systemic disease that is fundamentally connected to other diseases of inflammation, including diabetes, arthritis, Alzheimer's Disease, and heart disease; it is, therefore, not a disease that should be taken lightly (Friedewald, et al., 2009). According to (Papapanou, et al., 2018), "Periodontitis is a major public health problem due to its high prevalence. If left untreated periodontitis may lead to tooth loss which may negatively affect chewing function and aesthetics and cause a debilitated state, be a source of social inequality, and impair quality of life" (p. S174).

The tooth loss leads to masticatory dysfunction, resulting in substantial dental care costs for replacement options. Over time, patients may lose entire dentition and become edentulous, negatively impacting their general health (Papapanou, et al., 2018).

1.2 Prevalence of Periodontal Disease

After dental caries, periodontitis is the most prevalent disease affecting oral health. Current epidemiological estimates are that 11% of the world's population is affected by severe periodontitis, and its prevalence increases with age (Billings, et al., 2018). The National Health and Nutrition Examination Survey (NHANES) estimated that combined mild, moderate, and severe periodontitis affected more than 47% of the adult population from 2009 to 2010 in the USA (Eke, Dye, Wei, Thornton-Evans, & Genco, 2012). The Canadian Health Measure Survey (2010), a similar survey to NHANES, reported that 16% of Canadians had moderate and 4% had severe periodontal disease in 2010. As in the NHANES' findings, progressing age and smoking were two key factors associated with the progression of periodontal disease (Canada, Health).

1.3 Consequences of Periodontal Disease

The sequela of destruction caused by microbial deposits and host modulation depends on the severity of the periodontal disease and its rate of progression. Patients may or may not report a variety of symptoms, such as puffy reddish gums, spontaneous bleeding, pus, loose teeth (mobility), and receding gums. The increased bacterial load and weakened defense system of the periodontium cause the periodontal pockets to deepen, which in turn leads to loss of soft tissue and hard tissue (bone) around the teeth (Herrera, Retamal-Valdes, Alonso, & Feres, 2018).

As the bone support around the teeth is reduced, teeth start to move in two or three dimensions due to occlusal forces. They may move in a horizontal direction (bucco-lingual or mesio-distal planes), and/or, in cases of severe bone loss, they may move in a vertical direction (apico-coronally). This movement of teeth upon occluding or biting is called fremitus and at times causes discomfort to the patient as the masticatory efficiency deteriorates (Fan & Caton, 2018). Progressive bone loss may lead inevitably to tooth loss.

1.3.1 Tooth Mobility

According to Muhlemann (1967), tooth mobility can be broadly categorized into two groups: physiologic and pathologic (Muhlemann H. R., 1967). Physiologic tooth mobility, also known as normal tooth mobility, stems from the resilience of an intact and healthy periodontium (Giargia & Lindhe, 1997). Pathological tooth mobility results as a sequela of a quantitative and or qualitative alteration of the periodontium.

1.3.1.a Etiology of Tooth Mobility

- **Trauma from occlusion**

Trauma from occlusion (TFO) may be a major reason for tooth mobility. In the World Workshop 2017, (Fan & Caton, 2018) it is indicated that "Primary occlusal trauma is injury resulting in tissue changes from excessive occlusal forces applied to a tooth or teeth with normal periodontal support. It occurs in the presence of normal clinical attachment levels, normal bone levels, and excessive occlusal force(s). Secondary occlusal trauma is injury resulting in tissue changes from normal or excessive occlusal forces applied to a tooth or teeth with reduced

periodontal support. It occurs in the presence of attachment loss, bone loss, and normal/excessive occlusal force(s)" (p. S200).

- **Periodontitis**

Periodontitis leads to the loss of supporting alveolar bone, which provides most of the support for the teeth. Therefore, the extent of mobility is associated more with the critical mass of remaining alveolar bone support. This includes both the quantity and the quality of the alveolar bone support, and it is this critical mass of alveolar bone that allows for repair and regeneration of the periodontal ligament upon therapy (Muhlemann H. R., 1967).

- **Endodontic-periodontic lesions**

The bacterial proliferation at the apex of the teeth exudes toxins that devitalize the teeth by vexing the blood and nerve supply and by dissolving the surrounding bone. Extended inflammation from the root apex due to endodontic involvement in the periodontal ligament space leads to progressive bone loss around the tooth and in turn causes tooth mobility. Endodontic treatment should be performed to manage such mobility problems in primary endodontic and secondary periodontic lesions (Herrera, Retamal-Valdes, Alonso, & Feres, 2018).

- **Pathologies**

Cysts, tumors, osteomyelitis, and fractures due to trauma cause chronic inflammatory processes that dissolve the bone and other supporting structures around the teeth in the jaws. As

the support around the tooth is reduced, teeth become loose in the socket and maybe mobile. (Underbrink, Pou, Quinn, & Ryan, 2002).

- **Post-periodontal surgery**

The gingival fibres run in all directions from the tooth to the gingiva and help as anchors to the tooth. Following periodontal surgery, tooth mobility increases because all the supra crestal fibre attachments and the gingival fibres are severed when a flap is raised to access the periodontal defect. This mobility is mostly short lived, and typically in four weeks mobility decreases beyond pre-surgery levels as re-attachment of the periodontal ligament fibres and gingival fibres occurs due to healing (Persson, 1981).

1.3.1.b Stages of Tooth Mobility

- **Primary stage** (also known as initial or intra-socket stage): This movement within the confines of the periodontal ligament space occurs due to the viscoelastic distortion of the periodontal fluid and periodontal fibres content. This movement ranges from 50–100μm, under a load of 100lb (Muhlemann, Savdir, & Rateitschak, 1965). Consider Figure 1 below for a visual representation of Muhlemann's technique for measuring tooth mobility.

- **Secondary stage:** This movement occurs due to elastic deformation of the alveolar bone in response to increased horizontal force (Everett & Stern, 1969).

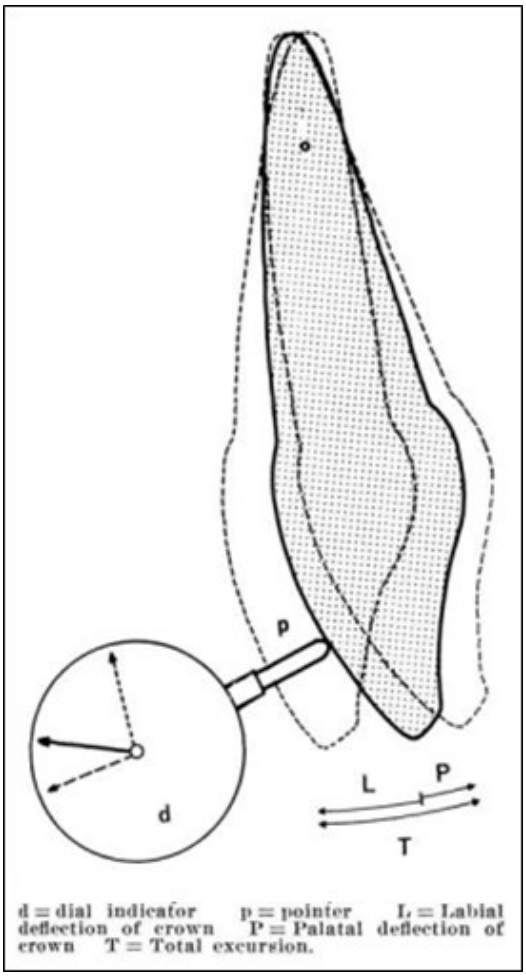


Figure 1: Muhlemann's technique of measuring tooth mobility and it's diagrammatic representation *(Mühlemann, 1960)*

1.3.1.c Measurement of Tooth Mobility

In 1950, Miller developed what would become the most frequently used method for determining clinical tooth mobility. As per his technique, the tooth is firmly held between two instruments and moved back and forth; the mobility is scored on a scale of 0 to 3 as follows (Miller, 1950):

- Grade 0: no detectable movement apart from physiologic tooth movement,
- Grade 1: greater than normal (physiologic) tooth mobility,

- Grade 2: mobility up to 1 mm in bucco-lingual direction,
- Grade 3: mobility >1 mm in bucco-lingual in combination with vertical depressability.

Though quite simple to use, Miller's technique for measuring clinical tooth mobility has the following limitations: 1) to choose the best therapy, it is critical to know if the mobility is a result of an adaptative process or a pathologic process, but Miller's technique fails to determine the cause of the mobility; 2) there is a marked variability among periodontists in discerning the grades of mobility based on Miller's classification as described by Laster, et al., in 1975 (Laster, Laudenbach, & Stoller, 1975).

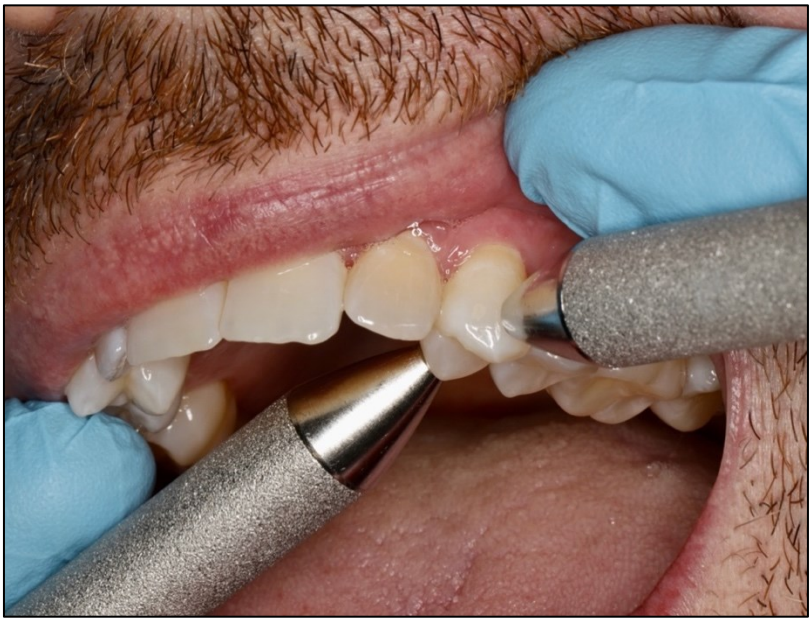


Figure 2: Clinical method of assessing tooth mobility by Miller's technique

Since Miller's technique was released, many other techniques and methods have been developed to measure tooth mobility: Periotest (1992), Resonance Frequency Analysis (1994), No Contact Vibration Device (2008), Zwick Method (2011), Konermann's Novel Intraoral Measuring Device (2016), and NEVD-Non-Contact Electromagnetic Vibration Device (2016). However, all these methods are time consuming, costly, too complex, and or impractical for routine clinical

application, and, at times require special training. Therefore, Miller's mobility classification is still the most used technique in clinical practices today (Varadhan, Parween, Bhavsar, & Prabhuji, 2019), as well as in our Graduate Periodontology Program (Figure 2).

1.4 Background

This section elaborates on the effects of vibration on bone mineral density (BMD). It presents evidence from the literature on in-vitro and in-vivo (both animal and human) studies in orthodontics, as well as pertinent literature from the field of periodontics. Details pertaining to the effects of vibration on BMD, effects of low-frequency vibration, and the effects of high-frequency vibration (HFV) on BMD and biological markers are also discussed.

1.4.1 Effects of Vibration on Bone Mineral Density

Treatment with vibration modality has been rigorously tested in medicine to prevent or minimize future bone loss in patients undergoing treatment for osteoporosis, muscular dystrophy, and cerebral palsy. A randomized clinical trial (RCT) of postmenopausal women confirmed that, while the subjects were standing on their feet, on a flat surface, on the ground, brief periods (<20 minutes) of a low-level (0.2g, 30 Hz) vibration applied (via an external device) to the spine and femur successfully inhibited bone loss, particularly in those with a lower body mass index (Rubin, et al., 2004). Another clinical trial confirmed increased BMD in young women by providing low-magnitude, high-frequency vibration for at least two minutes each day for 12 months. This non-invasive technique increased bone and muscle mass in the axial skeleton and lower extremities compared with control participants (Gilsanz, et al., 2006). In a pilot RCT performed on children with disabling conditions, a positive osteogenic potential of +6.3% in the BMD of the tibia was

reported in the intervention group, which received low-level mechanical stimuli of short durations. In the control group (no intervention group), there was a negative effect (-11.9%) on BMD, indicating that low-level mechanical stimuli represent a non-invasive, non-pharmacological treatment for low BMD in children with disabling conditions (Ward, et al., 2004).

1.4.2 Effects of Vibration in the Field of Orthodontics – Literature Review

One of the greatest challenges with orthodontic treatment is the time it takes to complete a case. On average, it takes up to two years to complete orthodontic treatment, and the treatment can last up to three years depending on the complexity of the case (Fink & Smith, 1992) (Tsichlaki, Chin, Pandis, & Fleming, 2016). Longer orthodontic treatment times even with controlled light forces (25g) can produce root resorption of teeth (Paetyangkul, et al., 2009). Therefore, a short duration of orthodontic treatment is desirable for both the orthodontist and the patient because the tooth roots are unlikely to be pathologically shortened (Farouk, Shipley, & El-Bialy, 2018).

Significant research has been done in the field of bone biology proposing numerous methodologies to shorten the time of orthodontic treatment. Both surgical and non-surgical methods have been developed to accelerate orthodontic tooth movement and shorten treatment times. The decision to use a surgical or non-surgical approach is determined by the orthodontist's practicing style and patient's choice. An example of a surgical approach is the Periodontally Assisted Osteogenic Orthodontics (PAOO) technique. Focussed decortications are made in the cortical bone and around the tooth root to provide stimulus to osteoblasts and osteoclasts to rapidly dissolve bone, promoting faster movement of teeth (Murphy, Wilcko, Wilcko, & Ferguson, 2009).

Non-surgical approaches include adjunctive vibratory mechanical stimulation to augment both orthodontic tooth movement and retention post treatment. Animal studies in orthodontics have

shown that when vibration at high-frequency (≥90 Hz) was applied to teeth for five minutes per day for 28 days, significant (159% greater) bone was formed around the teeth. In contrast, when vibration at low frequency (≤45 Hz) was applied to the teeth, no difference in bone formation was observed (Judex, Lei, Han, & Rubin, 2007). Many human studies in orthodontics have reported on the effects of using high-frequency vibration (120 Hz) for both catabolic and anabolic changes in the alveolar bone depending on the presence or absence of orthodontic forces (Shipley T. S., 2018). The catabolic effect of high-frequency vibration (HFV) in the presence of active orthodontic forces is due to increased inflammation in the periodontal ligament, which in turn induces exaggerated recruitment, differentiation, and increased proliferation of osteoclast cells. These osteoclast cells in turn degrade the bone and promote faster tooth movement (Alansari, et al., 2018).

The anabolic effect of the HFV on the alveolar bone is achieved through a process known as mechanotransduction in which mechanical signals (the vibration) are transduced into osteocyte bone cells and converted into biochemical energy (Liedert, Kaspar, Blakytny, Claes, & Ignatius, 2006). The embedded resident osteocytes in the bone have mechanosensory properties that are sensitive and highly adaptive to mechanical stimulation (Garman, Rubin, & Judex, 2007). The SOST gene found within the osteocyte cell produces sclerostin (a protein), which is a load-based regulator of bone density levels. When mechanical stimulation is applied to alveolar bone, the osteoclast cells upregulate the sclerostin level output by inhibiting Wnt signaling and favour the equilibrium towards regional osteogenesis, thus forming new bone (Alikhani, et al., 2019) (Robling, et al., 2008).

1.4.3 Effects of Vibration in the Field of Periodontics – Literature Review

With the intent of translating extensive research done on High-Frequency Vibration (HFV) in orthodontics to periodontics, a literature review was carried out to identify and understand the available literature. Three databases—PubMed, Scopus, and Ovid (Medline)—were searched with appropriate keywords to provide the available literature on the topic. Appendix B details the search strategy used for each database. A total of 1361 combined articles from three databases were extracted (PubMed–343; Scopus–555; Ovid (Medline)–463) from 1946 to 2022. Zotero (version 5.0.96.3), an open-source reference management software, was used to extract these citations and remove the duplicates.

After the duplicates had been removed, 579 articles were left, and the title and abstract were reviewed for each. The purpose of the title and abstract review was to identify articles that specifically discuss the effects of vibration (low-frequency or high-frequency), particularly on bone metabolism. Sixty-one articles were found to be relevant, the majority of which were studies related to orthodontic movement and tooth retention using vibration therapy. The above-mentioned literature on HFV and orthodontics was retrieved from these 61 articles and have been heavily referenced in this study. Only seven studies were found that examined the effects of vibration on the periodontal ligament and its surroundings. These seven studies were either in-vivo or in-vitro (animal studies).

An in-vitro study on stem and progenitor cell populations reported anabolic activity using low-magnitude and high-frequency (e.g., in a vibratory form) mechanical loads. The cells in the musculoskeletal system are sensitive to these mechanical signals, and this sensitivity can be applied to stem cell expansion, differentiation, and biomaterial interaction in tissue engineering applications (Baskan, Karadas, Mese, & Ozcivici, 2020). When investigating the effects of low-magnitude high-

frequency vibration (LMHFV) on proliferation, migration ability, and osteogenic differentiation of human periodontal ligament stem cells (hPDLSCs) in-vivo, Bai et al. (2019) found that the proliferation and migration abilities of hPDLSCs increased. Furthermore, at the genetic level, the expression level of RUNX2, ALP, Col-1, and OCN was significantly augmented under LMHFV, thus confirming hPDLSC proliferation, migration ability, and osteogenic differentiation (Bai, Hu, Li, & Wang, 2019). In another in-vitro study, human PDL cells were isolated from extracted premolar teeth and subjected to low-magnitude high-frequency (LMHF) vibration combined with compressive force on the periodontal ligament (PDL). Study results demonstrated that PGE2, RANKL, and soluble RANKL increased in the group that received vibration, but that OPG and Runx2 did not increase in the vibration group (Benjakul, Jitpukdeebodintra, & Leethanakul, 2018).

A 2018 in-vitro study published in the American Academy of Periodontology, Journal of Periodontology reported on human PDL cells under a combination of mechanical vibration and compressive force. The results demonstrated upregulated COX-2, IL-6, and IL-8 mRNA in hPDL cells and subsequently increased levels of PGE2, IL-6, and IL-8 in the culture medium via activation of the COX pathway. The study concluded that since PGE2, IL-6, and IL-8 are potent inducers of osteoclastogenesis, the mechanical vibration may increase alveolar bone resorption at the compression site during orthodontic tooth movement (Phusuntornsakul, Jitpukdeebodintra, Pavasant, & Leethanakul, 2018).

In 2020, an in-vitro study of a rat model demonstrated osteogenic differentiation potential of periodontal ligament stem cells (PDLSCs) at different time points using mechanical vibration stimulation. The animal model demonstrated that mechanical vibration at 150 rpm could be developed for the prevention of ankylosis and promotion of healing of the PDL after tooth replantation or transplantation (Chen, 2020).

Bio-stimulation of hard and soft tissue to enhance or accelerate healing is an exciting area of inquiry, with the potential to have broad clinical application in periodontics. The external application of energy in the form of light (e.g., lasers or broad-spectrum light) or mechanical waves (ultrasonic or high-frequency vibration) has shown efficacy in creating clinical changes in hard and soft tissue that can be positive and beneficial or the contrary, depending on the application and the initial conditions present (Carroll, Milward, Cooper, Hadis, & Palin, 2014) (El-Bialy, et al., 2020).

It is clear from previous research on the use of the HFV device to accelerate and enhance orthodontic therapy, that the cellular tissue response in areas of inflammation is essentially the opposite to that which occurs in areas of no inflammation. Improvement in bone density can translate clinically to lowering (i.e., improving) tooth mobility and to lessening the chance of orthodontic relapse after orthodontic therapy (Shipley, Farouk, & El-Bialy, 2019). Again, whether the response is beneficial depends on the intended application. HFV therapy in areas of inflammation caused by orthodontic tooth movement stimulates osteoclastic activity to accelerate the resorption of bone, making the bone "softer" and thus allowing for more rapid orthodontic tooth movement through these softer areas. On the other hand, when considering periodontitis, it is critical to understand that the inflammation must first be lowered and controlled so that the tissue response is anabolic, not catabolic. Our goal in periodontal therapy is to preserve, regenerate, and strengthen the periodontal tissues, including the bone. So, a mandatory precursor therapy to using HFV in cases of periodontitis is to first perform periodontal therapy and demonstrate and document a reduction or elimination of chronic inflammation by way of a re-evaluation examination.

Traditional and time-tested methods of treating periodontitis involve a meticulous mechanical cleaning of the root surfaces to remove the causal factors, both above and below the gum line. This reduction or elimination of the etiologic factors that trigger the pathologic and damaging immune response is very effective at reducing inflammation. When used as an adjunctive therapy following traditional treatment for periodontitis, during which the chronic inflammation has been lowered, controlled, or eliminated, HFV has the potential to enhance the mechanical properties of the bone by increasing bone density by way of a low-risk, non-invasive, self-applied therapy that is patient friendly and affordable (Alikhani, et al., 2018). No clinical study was found that directly studied the effect of HFV on tooth mobility per se. Therefore, we took the initiative to do the first ever pilot randomized clinical trial on human subjects.

1.5 Null Hypothesis

We hypothesize that there is no difference in tooth mobility before and after the use of an HFV device for five minutes per day for 12 weeks, either in the test group or the control group. Furthermore, we hypothesize that there is no difference in the BMD (expressed in Hounsfield units) before and after the use of an HFV device for five minutes per day for 12 weeks either in the test group or the control group.

1.6 Research Question

1. Will the vibration produced by the VPro+ device improve (i.e., lessen) the mobility of periodontally compromised teeth of periodontal patients in a periodontal recall program?
2. Will the vibration produced by the VPro+ device improve (i.e., increase) bone density as measured by CBCT analysis in periodontal patients in a periodontal recall program?

2. Materials and Methods

This chapter discusses the methods used to identify research participants, recruit them, collect data, and eliminate bias. It also introduces the devices and the technology used to collect data. Methods for data collection, tools and devices used for data collection, will be discussed and a chronological insight about the research project will be detailed.

2.1 Devices and Technology

2.1.1 The Periotest®M Device

Developed from 1972 to 1984 by an interdisciplinary group of researchers, the Periotest was intended to measure and understand the damping characteristics of the periodontal ligament. Dr. Schulte in Germany extensively experimented with the device and assessed the mobility of natural teeth and its relation to bone loss (Schulte & Lukas, The Periotest method, 1992). Based on the same principle, the Periotest®M Device (Medizintechnik Gulden, Modautal, Germany) is a modern wireless electronic device for measuring the mobility of teeth and osseointegration of dental implants (Schulte, d'Hoedt, Lukas, Maunz, & Steppeler, 1992). The device is an electro-magnetically driven and electronically controlled tapping metallic rod in a handpiece that percusses the tooth and then recoils. It measures the response reaction from a reproducible impact applied to the center of the tooth surface. During each measurement, the device delivers 16 impacts in four seconds to the object (tooth surface). The duration of contact of the tapping head on the tooth surface is measured by the instrument that quantifies the tooth mobility. The amount of tooth mobility is displayed by a value called the “Periotest value” (PTV) ranging from –8 to +50, which can be correlated to the grade of tooth mobility reported by Miller (Miller, 1950). Many

studies have shown the accuracy and reliability of the Periotest®M device and its clinical applicability (Chakrapani, et al., 2015) (Schulte, Luka, & Ernstt, 1990). Table 1 shows the clinical relation between grades of Miller's mobility and the PTV.

Table 1

Periotest values and their correlation to clinical tooth mobility

PTV and their correlation to clinical tooth mobility	
Periotest Values (PTV)	**Mobility Grade (Miller's)**
-8 to +9	0
+10 to +19	I
+20 to +29	II
+30 to +50	III

2.1.1.a Functioning of the Periotest®M device

The start button of the Periotest®M device is used to switch on the unit. All segments on the display light up for approximately two seconds. Then a short melody plays, the display screen lights up and shows **- -** , **-** and the Periotest®M is ready to conduct measurements (Figure 3). The start button is pressed again to begin the measuring process. The measuring cycle consists of 16 impulses of the pressure sensitive tapping head against the measuring object (tooth). For each valid impulse, a low tone is emitted. Invalid impulses, for example due to a too-high deviation from the correct posture of the Periotest®M, are followed by a high tone. The posture of the Periotest®M is then corrected during the measuring process.

Figure 3: The Periotest®M device

A certain distance between the tip of the probe and the tooth is needed for the device to function properly. The valid distance is between 0.6 and 2.5 millimeters. If the device is held closer than 0.6 mm or further away than 2.5 mm, there is no valid reading. After the measuring cycle (approximately four seconds) is finished, the short melody plays again. At least four of 16 impulses must be valid to obtain a valid reading on the display. These instructions are described by the manufacturer of the periotest device on how to use the device, on how the mechanics of it work (Medizintechnik Gulden). They do not provide a recommendation for how to deal with error messages and that a protocol for doing so will be described in section 2.6 below.

2.1.2 PTech Vibration Device

At the initiation of the research project, Propel Orthodontics (Milpitas, California, USA) distributed the VPro+ vibration devices for use in the field of orthodontics. By the time we started recruiting research patients for this research project, VPro+ device technology was sold to another company by the name of PerioTech Limited (PerioTech LLC.). Subsequently, the VPro+ device was rebranded as the PTech vibratory device, but in actuality is the same device.

Figure 4: The PTech vibratory device

PerioTech Limited donated 12 active PTech vibratory devices and 12 sham PTech vibratory devices for our research project (Figure 4). The research participants were given a PTech vibration device and instructed how to use it (Figure 5). They were told that biting down gently on the mouthpiece during use is sufficient and that there was no need to bite down harder than needed to support the device (Propel Orthodontics). To activate it, press the button present on the device. Research participants in both groups were expected to use this device for five

minutes every night before bedtime for a period of three months. The device automatically records compliance data when connected to a Bluetooth enabled mobile device that has the device app downloaded and automatically shuts off after five minutes. The person using the device needs to pair the device with the mobile app at least once a week for it to record number of minutes it was used in last seven days. Research participants were asked to use a mobile phone app to collect compliance data and periodically synchronize the data online in the mobile app. Research participants were instructed to bring the device back with them to their next visit in three months. The device was collected from all the research participants upon completion of the research study.

Figure 5: The PTech vibratory device in action in patient's mouth

2.1.3 Cone-beam Computed Tomography

Cone-beam computed tomography (CBCT) is a form of computerized tomography (CT) that has been engineered for imaging in the maxillofacial region. Introduced in 1996 in Europe and in 2001 in the USA, this technology has revolutionized the diagnostic capabilities of dental clinicians (Ludlow, et al., 2015). One of the biggest advantages of modern day CBCT is its ability to provide an acceptable image quality with a significantly lower dose of radiation exposure when compared to medical grade computed tomographic radiography (mCT). In today's world, CBCT has become both general and specialist dentists' tool of choice to assess the quantity and quality of bone before placing dental implants, endodontic therapy etc. because of the diagnostic advantages when compared to two-dimensional imaging (Mah, Reeves, & McDavid, 2010) (Reeves, Mah, & McDavid, 2012).

A CBCT scan helps dentists to study the anatomy of the teeth and the surrounding mineralized structures such as bone in three dimensions. Previously it was believed that the quantification of bone mineral density (BMD) in Hounsfield units (HU) from a CBCT was unreliable and should not be used (Silva, Freitas, Ambrosano, Boscolo, & Almeida, 2012). However, with recent advances in technology and newer CBCT machines, the reliable quantification of BMD in terms of HU using grey levels in the CBCT volume has been well demonstrated in the literature. (Mah, Reeves, & McDavid, 2010) (Reeves, Mah, & McDavid, 2012).

A 2017 American Academy of Periodontology systematic review describes a calibration curve to obtain accurate quantitative BMD measurements in HU from CBCT gray values (Rios, Borgnakke, & Benavides, 2017). It is pertinent to mention here that HU values obtained from CBCT do not represent absolute HU values as derived from multidetector CT (mCT). However, the HU

values calculated using CBCT provide adequate information relative to changes in BMD for comparative purposes within and between patients (Reeves, Mah, & McDavid, 2012).

2.1.3.a Hounsfield units

As per (Pauwels, Jacobs, Singer, & Mupparapu, 2015), "Hounsfield units (HU) are defined as linear transformations of measured X-ray attenuation coefficients of a material with reference to water. Hounsfield units can be calculated for any material using the formula:

$$HU_{material} = 1000 \times \frac{\mu_{material} - \mu_{water}}{\mu_{water}}$$

wherein $\mu_{material}$ and μ_{water} are the linear attenuation coefficients for the material and water, respectively" (p. 3). According to the authors, "the Hounsfield unit scale is based on two fixed values, which are 0 HU for water and -1000 HU for air ($\mu_{air} = 0$)" (p. 3). The study also stated that the materials or tissues that absorb more X-rays (for example, bone) tend to have a higher Hounsfield unit value.

To measure the change in BMD, if any, due to the HFV device, a baseline (t_0) CBCT was taken and a second CBCT for comparison was taken at three months (t_1). For our research study, we used 0.3 mm voxel size, 8 cm X 8 cm (maxilla and mandible included), 8.9 seconds exposure time to reduce the radiation dose to the patient. The CBCT dose ranges from 50µSv (micro sievert) to 1,000µSv in general for dental use. For periodontal patients, the protocol dose is delivered around 150µSv (Jacobs, Salmon, Codari, Hassan, & Bornstein, 2018) (Tyndall, et al., 2012). The same parameters were used for the CBCT acquisition at three months (t_1).

2.1.3.b Calculation of Bone Mineral Density

Using InVivo Dental 6.0 (Anatomage Inc., San Jose, CA, USA), Digital Imaging and Communications in Medicine (DICOM) was used and BMD was calculated between all the existing teeth. On the acquired CBCT scan, each arch axial plane was scanned until all the existing teeth roots were seen surrounded by the bone around them. A mid-point was chosen traversing from buccal to palatal/lingual aspect, and a rectangular box was drawn using the HU button/feature in the software. The surface area measured in the box was ≥ 0.995 mm$^2 \leq 0.999$ mm^2. A value was generated by the software depicting HU and was recorded in an Microsoft Excel spreadsheet. The screenshot of the entire arch (maxillary/mandibular) was captured and kept as a record to match with the position of the plane and rectangular box for measuring the HU on the CBCT scan at three months (t_1). See Appendix C for a visual description of the above elaborated process for calculation of the HU.

2.2 Sample Size Calculation

The primary research objective was to compare mean tooth mobility between the control group and the test group. The minimum observable difference was change in the Miller's mobility from grade 2 to grade 1 or from grade 1 to grade 0. The corresponding change in the PTV can be corroborated based on the Table 1 mentioned above in section 2.1.1 above. The estimated sample size was a minimum of 51 mobile teeth per group, for a total of a minimum of 102 mobile teeth in total. The estimation was based on a type I error rate of 0.05, a type II error rate of 0.2 (i.e., statistical power=0.8), and a medium effect size of 0.5. The effect size was defined as dividing two population mean differences by their standard deviation (Chow, Shao, Wang, & Lokhnygina, 2017).

2.3 Study Design

This study was a randomized, double blind pilot clinical trial research model comprising a test group and a control group. After the ethics approval was received from the Health Research Ethics Board (HERB) – Health panel at the University of Alberta (Pro00102774), custodian agreements were signed by the Principal Investigator. Upon satisfactory completion of the custodian agreements, a query was run by the clinic coordinator for potential patients. A periodontal patient was defined as a patient who has been diagnosed with periodontal disease (loss of attachment and supportive bone structure) and has received treatment in the Graduate Periodontology Program at the University of Alberta. Once active (non-surgical and/or surgical) periodontal treatment was complete, these patients needed to be on regular maintenance supportive periodontal therapy (regular dental cleaning) every three to four months. In our Graduate Periodontology Program, we have such patients who come for regular maintenance supportive periodontal therapy. They are seen by our hygienist and the Graduate Periodontology students. The query was run to determine active periodontal patients in the Graduate Periodontology Program who had a minimum of two periodontal maintenance appointments/visits completed in the previous 12 months. A list of 243 patients was obtained based on the requested query from the axiUm database.

2.3 Individuals on the Research Team and their Respective Roles

The HFV study was a thesis research project by Sameer Bajaj, a student in the Graduate Periodontology Program at the University of Alberta. In his role as the Graduate Student (GS) in the project, he called and recruited the potential research patients. He also collected data at baseline (t_0) and a three-month assessment (t_1), including but not limited to periodontal indices, Periotest readings (PTV), and CBCT bone density findings (HU). Thereafter, GS extracted all the research

data, analyzed them, and prepared the manuscript. Dr. Douglas Dederich was the Principal Investigator (PI), and he oversaw every step from research proposal to ethics approval, timing, methods for data collection, and allocation of resources. Both the PI and the GS were double blinded in the study.

The treatment coordinator (TC) of the Graduate Periodontology Program was involved in logistics management. The treatment coordinator's role included but was not limited to sending out and receiving the signed consent forms, booking baseline (t_0) and three-month assessment (t_1) appointments, and randomly allocating the patients to the test group or control group at the end of the baseline (t_0) appointment. Furthermore, TC maintained a confidential log of the patients and the devices (active versus sham) provided to them. TC was responsible for collecting the devices at the end of the three-month assessment (t_1) appointment, which corresponded with the end of the study. Lastly, the TC maintained a separate log for noting the compliance of the patients in using the HFV device as recalled by the patient.

At the end of the data collection, the TC provided the GS list of patient chart numbers labeled as group 1 and group 2. TC did not disclose the test group and control group allocation. By this method both, the PI and the GS were double blinded and not aware of the group allocation. Once the results of the analysis were presented by the GS to the PI, the TC upon principal investigator's recommendation released the actual list of patients who were in the test and control groups to the GS to report results in the manuscript accordingly.

2.4 Research Participants

In answer to the axiUm query, 243 chart numbers were received, which were input into a Microsoft Excel spreadsheet. Each chart number was assigned a separate row, and columns were designated for age, gender, number of supportive periodontal therapies (also known as

periodontal maintenance (MSPT) visits/appointments), use of bisphosphonates, smoking status, diabetes status, ASA classification, periodontal disease under control, number of mobile teeth and their grade, and whether the patient qualified for the study. Each chart was read in depth to understand the medical history, periodontal condition (active disease versus non-active disease), number of mobile teeth, and then the values in each row and column were input accordingly into the Excel spreadsheet. See Appendix D for a sample of the Microsoft Excel spreadsheet used for this process.

2.5 Selection Criteria

2.5.1 Inclusion Criteria

1. Overall health must be either ASA Classification I or II. (ASA I: A normal healthy patient; ASA II: A patient with mild systemic disease) (Doyle, Goyal, & EH, 2022),
2. Patient must have a recent history of treated periodontal disease and currently be compliant with a periodontal recall maintenance program supervised by a periodontal specialist,
3. Patient age must be between 30 and 85 years,
4. No gender or ethnic restrictions,
5. Patient must have at least one tooth with Miller's Class I mobility,
6. Patient should have posterior dentition such that they can firmly hold the vibrating device, this likely implies the presence of two or more posterior teeth in all four quadrants.

2.5.2 Exclusion Criteria

1. Patients on medication that could affect the level of inflammation, such as chronic antibiotics, phenytoin, cyclosporine, anti-inflammatory drugs, systemic corticosteroids, or calcium channel blockers,
2. Periodontal recall patients who have a history of non-compliance with the recommended recall interval (usually three to four months),
3. Pregnant women,
4. Uncontrolled diabetes,
5. Smoking,
6. Subjects with current caries activity,
7. Vulnerable subjects as per the Research Ethics Office or HREB definitions.

Thirty-three patient charts were identified for participation in the study after thorough scrutiny based on the above-mentioned inclusion and exclusion criteria. The GS developed a standardized script, which was used to communicate with these potential research participants/patients (Appendix E). The patients were contacted by telephone and informed about the research study. Patients were made fully aware on the telephone call that they did not have to be in this study to receive their periodontal maintenance therapy at the Graduate Periodontology Program, School of Dentistry, University of Alberta. Further, even if they agreed to be in the study, they were told that they would be free to withdraw at any time and that if they did so, their periodontal care would not be affected in any way. Lastly, patients were advised that they would not receive any payment for being in this study; however, the treatment they received as part of this study would be at no cost to them.

Twenty-two patients expressed interest in participating based on the telephone conversation. The treatment coordinator sent the consent forms (Appendix F) to these patients via email or mail, as preferred by the patients. Nineteen patients agreed and consented to voluntarily participate in the research, and the treatment coordinator booked them for two consecutive appointments for baseline (t_0) and three-month assessment (t_1). These two appointments were made 12 weeks apart. Each appointment was booked for one hour and 30 minutes for collecting the data, which included a complete periodontal examination, a medium field CBCT, and the provision of supportive periodontal therapy (SPT). A timeline indicating the activities performed in each visit can be found in Table 2 and Table 3 below.

Table 2

Activities in the baseline appointment (t_0)

Obtain informed consent (done via email or mail if possible)	15 min
Complete patient health history form (done over the phone if patient agrees)	20 min
Complete periodontal examination by Graduate Student (GS)	30 min
Randomize and assign patients into control/experimental groups by treatment coordinator (TC)	5 min
Periodontal recall cleaning (by GS), and the patients receive the device from the TC	55 min
Total appointment time	**90–125 min**

Table 3

Activities in the three-month appointment (t_1)

Complete Periodontal Examination by GS	30 min
Periodontal recall cleaning is done by GS, and the device is collected from patients by the TC	60 Min
Total appointment time	**90 min**

Both the GS and the PI were double blinded in the study. The TC was provided with an Microsoft Excel spreadsheet with the number of mobile teeth in all the 19 patients, as noted on their last annual periodontal re-evaluation. At the end of each patient's first appointment (baseline (t_0)) in the research study, the patient was randomly allocated to either the test group or the control group. The random allocation was done based on the number of mobile teeth and to obtain a minimum of 51 clinically mobile teeth in both the test group and the control group.

Patients allocated to the test group received a device that would vibrate when turned on, its charging cord, and an instruction manual. Patients allocated to the control group received a sham device. Participants in both groups were asked to maintain a log on their use of the device for the following 12 weeks. Patients were given a printed pamphlet with instructions to download a mobile app (android and iPhone) that would connect with the device wirelessly (Appendix G) via Bluetooth and record compliance data (minutes used per day). The participants were requested to sync their device and the app at least once per week. In the event they were not able to use the mobile app, patients were requested to maintain a paper log to self-report number of minutes per night during which they used the device, as well as the number of days. In the event of the paper log, participants were requested to document the use of the device on daily basis before going to the bed. Any questions from subjects related to the device, its usage, its functioning, and log maintenance were delegated to the TC.

One patient withdrew their consent in the middle of the study and did not return for the three-month follow-up appointment. Another patient was not included in the study as she reported she was pregnant on the day of her baseline examination appointment. Seventeen patients completed the research study and returned their devices at their three-month data collection appointment. When collecting the device (from both the test group and the control

group), the TC asked for the log from the patients that depicted minutes of use per day and the number of days the device was used in past 12 weeks.

The majority of the patients were elderly, and they reported that they were not well-versed with technology (use of smart phone apps). They, therefore, logged their time on paper once a week. At the end of the study, they informed the TC about the same who updated our system log based on the estimate provided by the patients. All the patients in the test group (eight patients) confirmed that they had used the device for five to six minutes per day for at least 11 to 12 weeks Patients reported that unless they were not at home for the weekend and did not carry the device, they used it religiously as they very much wanted the HFV device to tighten their loose teeth and save their remaining dentition. The chronology of the study is summarized in CONSORT flow diagram (Schulz, Altman, & Moher, 2010) shown in Figure *6* on next page.

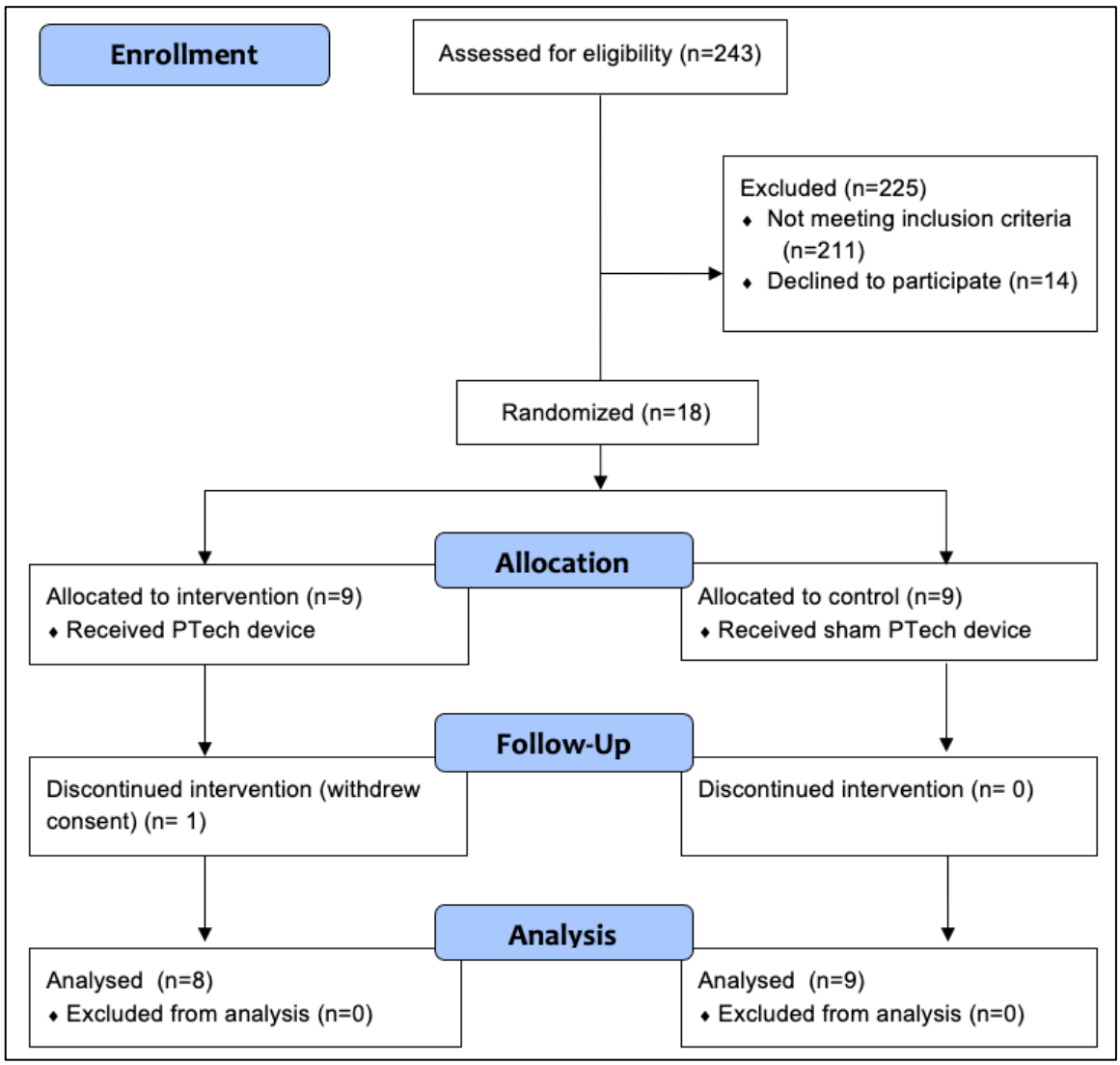


Figure 6: CONSORT flow diagram of research participants recruitment

2.6 Methodology for Data Collection in Each Appointment

The patients were checked-in by the Graduate Periodontology treatment coordinator who reiterated the purpose and flow of the baseline (t_0) examination appointment to the patient and then escorted the patient to the graduate student's dental chair. The patient was greeted and thanked by the graduate student (GS) for agreeing to voluntarily participate in the research project. With the help of a chairside Registered Dental Assistant (RDA), a complete periodontal examination was performed, including collecting all the values on all the teeth in the periodontal chart. Indexes collected were probing depths, bleeding on probing, clinical attachment levels, Miller's grade of mobility, recession, furcations, and mucogingival involvement. A Periotest M device was used to calculate the PTV values of all the teeth (Figure 7).

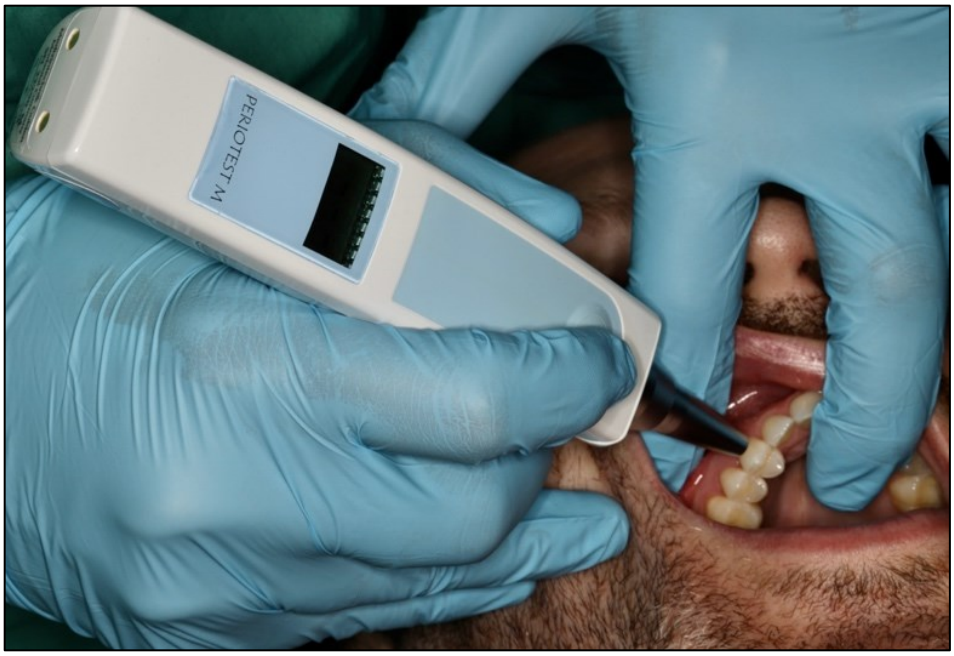


Figure 7: Clinical method of using the Periotest®M device

The GS explained to the patient in layman's terms how the Periotest®M device functioned and then demonstrated how the device worked on their fingernail to show them the pressure exerted by the oscillating part of the device. This demonstration exercise on the

fingernail helped to ease the patients' anxiety about the amount of vibratory force exerted by the Periotest device. Then, PTV measurements were made of all the teeth present in the mouth, starting from quadrant 1 to quadrant 2 (tooth 18 to 28) and then from quadrant 3 to quadrant 4 (tooth 38 to 48) as shown in Figure 8. During the data collection, data was collected on all the teeth of patients in chair rather than specific mobile teeth identified in the chart. This made it easy for the graduate student to measure periotest values in a flow in the entire dentition eliminating any possible measurement bias by just focusing on the mobile teeth. Furthermore, this also helped to boost patient's morale of retention in the research participation as they were willing to get all their teeth tested by the Periotest device.

Figure 8: The Periotest®M device in action with a reading

Readings were taken once by pointing the Periotest®M device 0.6 mm-2mm away from the tooth hitting perpendicularly at the height of the contour of the clinical crown. Teeth that did not generate a PTV reading, or if the device gave an error message in the first round were left, and another reading was attempted after all the teeth were tested once. If the Periotest®M device did not generate a reading for the second time, a last attempt was made after a pause of two to

three minutes, but only if the patient was comfortable with another attempt. The GS waited for two to three minutes before making an attempt to record PTV for two reasons, 1) to let the periodontal tissue return to normal for accuracy of the measurement, respecting the latency period and 2) to make the experience less overwhelming for the patient, swallow saliva in the mean while and relax their jaw.

The PTV value was voiced by the GS and was noted by the RDA using pen and paper in a table format (Appendix H). Next, supportive periodontal therapy was provided by the GS at no charge to the patient. Then, the RDA escorted the patient to the radiology department for a medium field CBCT, which included the maxilla and mandible along with the temporomandibular joints (TMJ). Lastly, the patient was escorted to the Graduate Periodontology reception kiosk, where the TC allocated them to a test or control group and, accordingly, provided them with a device.

2.7 Data Extraction

At the end of the day of each patient's appointment, the PTV data from the paper sheet was input into a Microsoft Excel spreadsheet, and the original paper sheet was scanned to convert it into a digital format for storage with the custodian (the Principal Investigator). Please see Appendix I for a visual description of the above elaborated process for documentation of the PTV. Additionally, the acquired CBCT was used to determine the HU to measure BMD at the mid-root of the tooth and at the mid-point bucco-lingually for the mandibular arch and at the mid-point bucco-palatally for the maxillary arch, as explained in 2.1.3.b Calculation of B. This entire process of data extraction was repeated for all 17 patients at baseline examination (t_0) and

at their three-month assessment visit (t_1). See Appendix I for a visual description of the above elaborated process for documentation of the HU.

3. Results

3.1 Reliability Test for Periotest Value Measurement

To ensure the graduate student (GS) in the study could accurately use the Periotest®M device, intra-rater reliability testing was completed. Five repetitive measurements of Periotest value (PTV) values were recorded on all the 24 teeth of a volunteer co-resident in the Graduate Periodontology Program using the Periotest®M device on five separate days. We took readings on every Monday during the lunch hour for five consecutive weeks. The readings were taken one week apart from the previous reading to account for latency errors if any and determine the reliability of the graduate student at different times rather than taking back-to-back measurements on the same co-resident. It took five weeks to collect the data for reliability testing. The recorded PTV values were transferred to a Microsoft Excel spreadsheet. Using IBM SPPSS version 26, the intraclass correlation coefficient was calculated as 97.8% (p<0.001) with a 95% confidence interval (CI) of [0.961, 0.989]. The intraclass correlation coefficient (ICC) tells us about the reliability of the person (in this case the graduate student) collecting the data and ensures that the process was consistent and robust. In general, an ICC score above 90% is considered acceptable for clinical studies.

3.2 Reliability Test for HU Measurement

All the measurements for the Hounsfield units (HU) were done by the GS. To confirm the reliability of the GS for accurately determining the HU for this research project, intra-rater reliability testing was completed. Five repetitive measurements of HU values were determined on all the 28 teeth of a randomly chosen patient who had a CBCT done in the Graduate Periodontology Program. These HU values were determined from the same CBCT on five separate days in two

months. Each reading was taken at least one week apart from the previous reading. The recorded HU values were transferred to a Microsoft Excel spreadsheet. Using IBM SPPSS version 26, the intraclass correlation coefficient was calculated as 98.9% (p<0.001) with a 95% CI [0.980, 0.994]. The intraclass correlation coefficient (ICC) tells us about the reliability of the person (in this case the GS) collecting the data and ensures that the process was consistent and robust. In general, an ICC score above 90% is considered acceptable for clinical studies.

3.3 Data Description and Details of Specific Analysis

While in the initial stages of the development of this pilot randomized clinical trial, we hypothesized that the estimated sample size was a minimum of 51 mobile teeth per group, for a total of a minimum of 102 mobile teeth in total. These mobile teeth were based on the ones noted in the patients' chart in their last annual periodontal recall examination done in the graduate periodontology department at the University of Alberta in last one year. The estimation was based on a type I error rate of 0.05, a type II error rate of 0.2 (i.e., statistical power=0.8), and a medium effect size of 0.5. During the data collection, data was collected on all the teeth of patients in chair rather than specific mobile teeth identified in the chart. By choosing this method, the GS measured PTV in a flow in the entire dentition eliminating any possible measurement bias by just focusing on the mobile teeth. Furthermore, this also helped to boost patient's morale of retention in the research participation as they were willing to get all their teeth tested by the Periotest®M device.

Since we collected the data points on every single tooth in all the 17 patients, two separate data analyses were performed. We started with the larger data set that had all the teeth (n=423) and then performed a sub-analysis on the teeth determined to be clinically mobile by the Miller's classification during the initial examination (n= 116). Notably, for achieving statistical power we

needed a minimum of 102 mobile teeth in total, but we had 116 mobile teeth noted in these 17 patients. In the following sections, the results will be discussed separately for the entire data set and separately for the target teeth (mobile teeth)

3.4 Data Transformation for the Entire Data Set

The digitized data was further transformed using Microsoft Excel version 16.60. Of 423 teeth, seven were identified as missing the PTV and therefore were removed from the analysis. Therefore, a total 416 teeth were available with PTV values at baseline (t_0) and at three months (t_1). Statistical analyses for PTV were conducted on measurements taken on all these 416 teeth. They were arranged in Microsoft Excel with each tooth occupying an independent row and subsequent columns had the PTV at baseline (t_0) and three months (t_1). The third column consisted of the identification from the test group versus the control group. Similar transformation was done for the BMD calculated in HU. In total 397 teeth were available for HU values at baseline (t_0) and at three months (t_1). While deducing the HU values from the CBCT, teeth which were adjacent to dental implants, root canal treated teeth and other restorative material that caused a lot of scatter were removed as it made calculation of the HU very challenging. Therefore, HU were measured only on 397 teeth and not entire 423 teeth. Statistical analysis for HU were conducted on measurements taken on all these 397 teeth. See Appendix I for visual representation of the data transformation explained above both for the PTV and HU.

3.5 Data Analysis for the Entire Data Set (n=416)

3.5.1 Data Analysis for the Periotest Value (PTV) for the Entire Data Set (n=416)

The transformed data was imported into IBM SPSS software version 26. The outcome variable measured was the Periotest value (PTV). Two factors responsible for affecting the outcome variable were identified as time and group; each with two levels. The factor "group" had two levels – test and control. Similarly, the factor "time" had two levels – baseline (t_0) and three months (t_1). A one way repeated-measures ANOVA for dependent samples, was conducted to assess whether there were differences in the mean PTV in the test group as compared to the PTV in the control group at three months. Hypothesis testing was carried out pertaining to the statistical test of choice.

Using the main outcome variable PTV, a boxplot (Figure 9) was developed to visually assess of the distribution of the data. The box plot indicates that the spread of the PTV for both the control and the test group at baseline (t_0) and at three months (t_1) and that the sample was normally distributed. The confidence interval (CI) for the mean PTV in the control group at a baseline (t_0) was 4.864 ± 0.343 with a 95% CI [4.183, 5.545], and at three months (t_1), it was 5.265 ± 0.383 with a 95% CI [4.510, 6.021]. The confidence interval (CI) for the mean PTV in the test group at baseline (t_0) was 6.962 ± 0.471 with a 95% CI [6.032, 7.892], and at three months (t_1), it was 7.126 ± 0.485 with a 95% CI [6.169, 8.082]. The detailed descriptive summaries and associated output generated from IBM SPSS software version 26 can be seen in Appendix J.

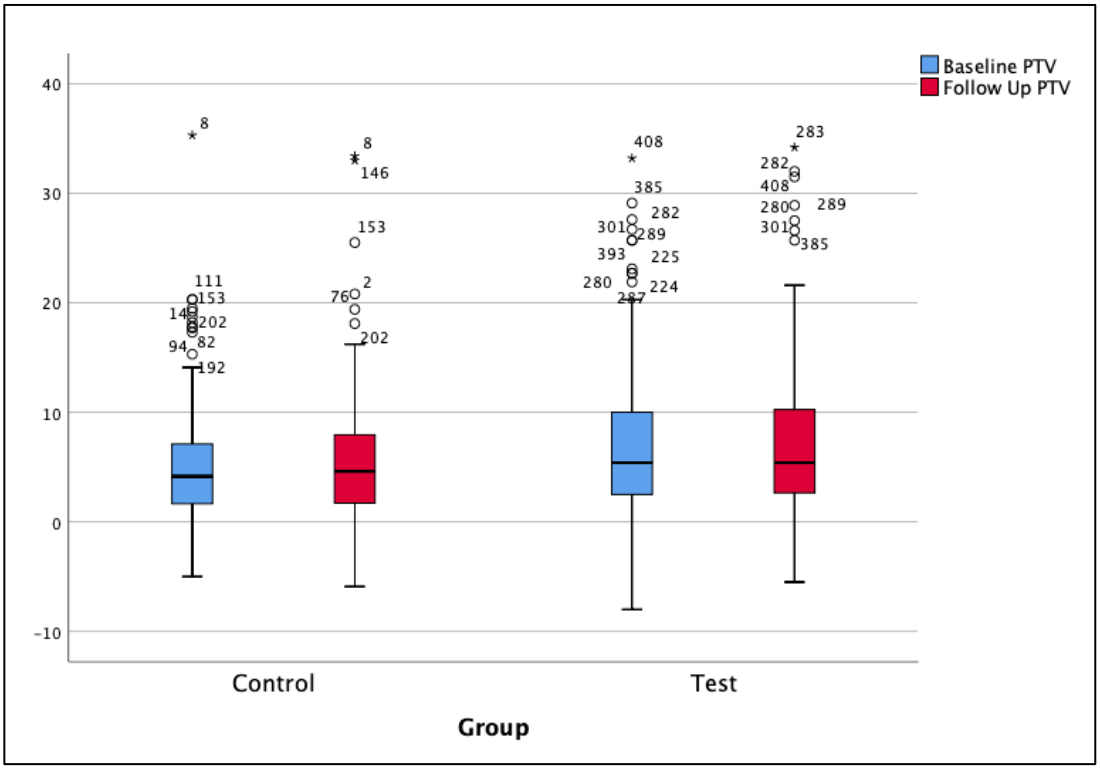


Figure 9: Boxplot depicting distribution of the Periotest values (PTV) for test and control group (n=416)

Test of Within-subjects effects

The test of within-subjects effects results indicated that there was no significant difference in the mean PTV at baseline (t_0) and at three months (t_1). The Greenhouse-Geisser test statistic was as follows: [F(df=1)=2.689, p=0.102].

Test of Between-subjects effects

The test of between-subjects effects results indicated a significant difference in the mean PTV between the test group and the control group. The associated test statistic was as follows: [F(df=1)=12.105, p=0.001]. The results of the pairwise comparison using the least significant difference (LSD post-hoc test) between the control and the test group revealed a mean difference in the PTV value of 1.979 (p=0.001) with a 95% CI [0.861, 3.097].

Test for Interaction between factors

The test for interaction results indicated no interaction between the two factors: group and time. The associated Greenhouse-Geisser test statistic was as follows: [F(df=1)=0.475, p=0.491], indicating that the differences in mean PTV between test and control were the same.

3.5.2 Interpretation of the Results for the Periotest Value for the Entire Data Set (n=416)

A pairwise comparison was done between the mean PTV values of the teeth at baseline (t_0) and at three months (t_1) in the test group. The PTV value at three months (t_1) was 0.164 units (p=0.514) higher than the value at baseline (t_0) and was statistically not significant (Appendix J). The evidence provided by the data supports that there was no difference in the PTV value of teeth at baseline (t_0) and at three months (t_1). The use of HFV via the PTech device for 12 weeks did not show a statistical change in the periotest value (PTV) in the test group. Notably, the mean PTV increased in both the test and the control groups from baseline (t_0) to three months (t_1) but the change was not statistically significant. These results are further elaborated based on the visual representation in Figure 10 on the next page.

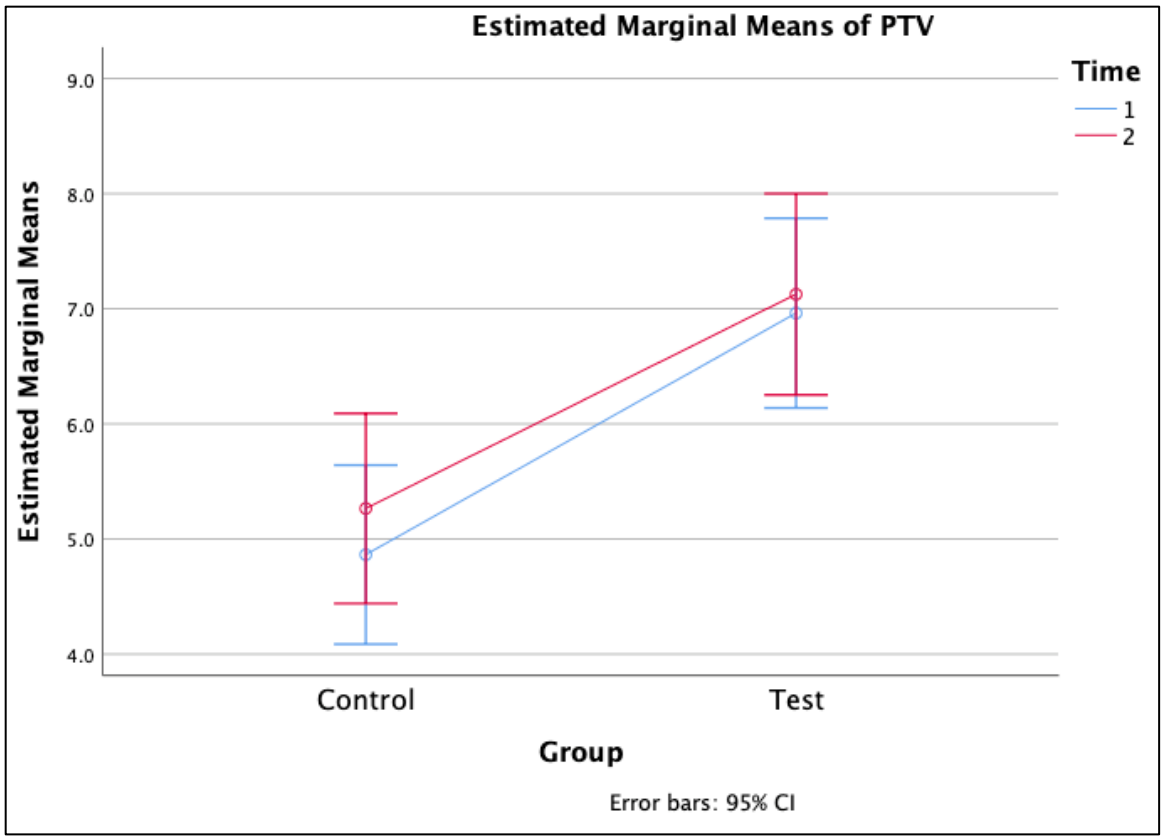


Figure 10: Profile plot depicting estimated marginal means of the Periotest value (PTV) for the test and control groups (n=416)

The profile plot in Figure 10 depicts the estimated marginal means of both the test group and the control group at baseline (t_0) (blue in colour) and at three months (t_1) (red in colour). The group (test versus control) is depicted on the x-axis. The y-axis represents the mean PTV. In both the test group and the control group, the confidence interval of the mean PTV at baseline (t_0) (blue in colour and numeral 1) and at three months (t_1) (red in colour and numeral 2) overlap, indicating that the mean PTV are same in both the groups at baseline (t_0) and at three months (t_1). This result corresponds with the calculated test statistic and the associated p-value for the test of within-subjects effects. The Greenhouse-Geisser test statistic was as follows: [F(df=1)=2.689, p=0.102]. Notably, by the process of randomization the research participants who were allocated to the test group had higher PTV to begin with as compared to the control group. The mean difference in the

PTV value was 1.979 (p=0.001), but this numerical difference in PTV does not make a clinical difference in the tooth mobility.

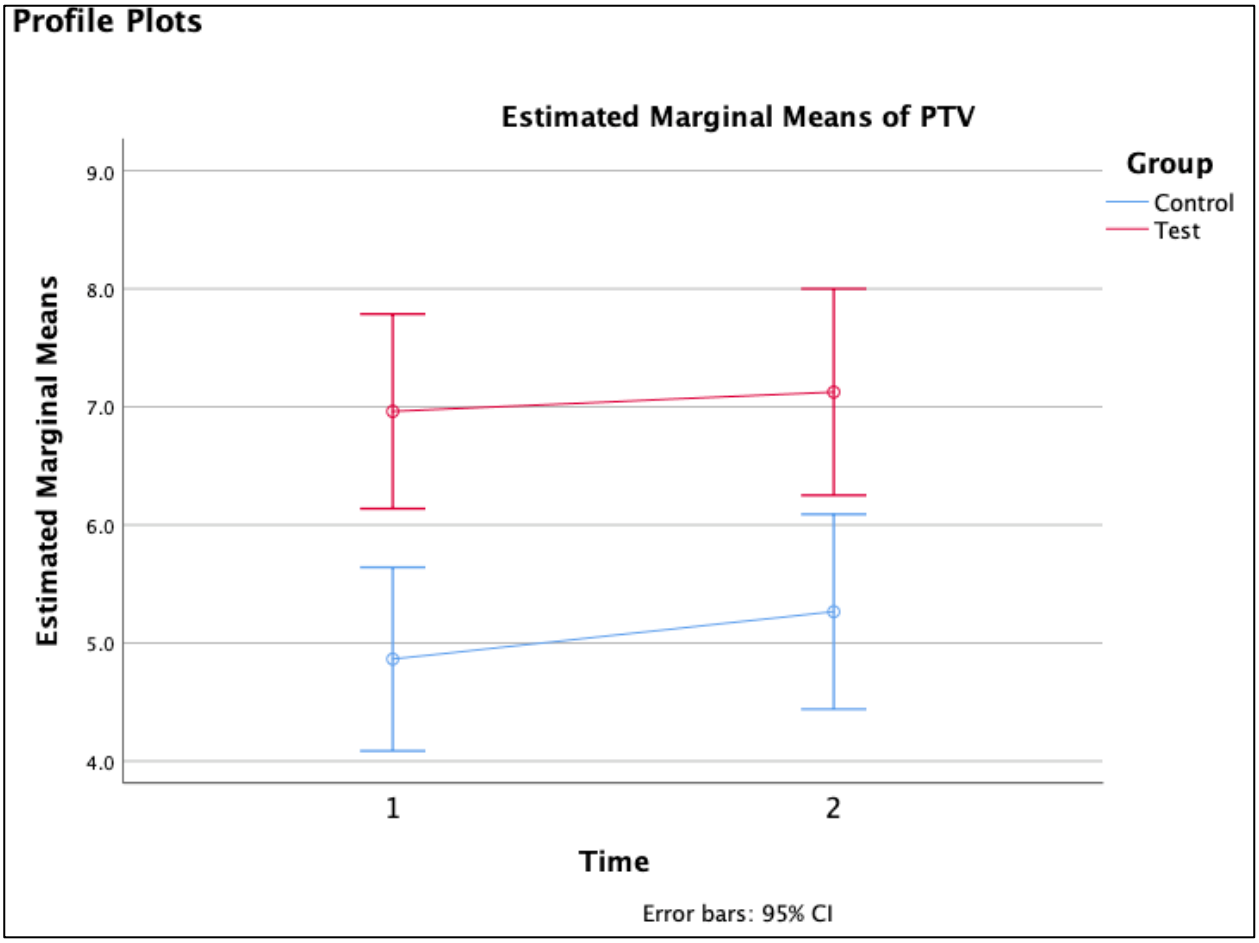


Figure 11: Profile plot depicting estimated marginal means of the Periotest value (PTV) at time: baseline (1) and three months (2); (n=416)

The profile plot in Figure 11 depicts the estimated marginal means at baseline (t_0) and at three months (t_1) of both the test group (red in colour) and the control group (blue in colour). Time is depicted on the x-axis. The y-axis represents the mean PTV. The numeral 1 represents the baseline (t_0) and the numeral 2 represents the three months (t_1). At baseline (t_0) (i.e., time 1), the confidence interval of the test group and the control group do not overlap, indicating that the mean PTV differs in both groups at baseline (t_0). The higher mean PTV of the test group was evident from

the profile plot due to the corresponding value of the mean PTV on the y-axis. A similar trend was seen at three months (t_1) (i.e., time 2). Here the confidence interval of the test group and the control group do not overlap, indicating that the mean PTV differ in both groups at three months (t_1). The higher mean PTV of the test group was evident from the profile plot due to the corresponding value of the mean PTV on the y-axis. This result corresponds with the calculated test statistic and the associated p-value for the interaction term. The Greenhouse-Geisser test statistic was as follows: [F(df=1)=0.475, p=0.491].

3.5.3 Data Analysis for the Bone Mineral Density in Hounsfield units (HU) for the Entire Data Set (n=397)

The transformed data was imported into IBM SPSS software version 26. The outcome variable measured was the BMD measured in Hounsfield units (HU). In total, 397 teeth were available for HU values at baseline (t_0) and at three months (t_1). The two factors affecting the outcome variable were time and group, each with two levels. The factor group's two levels were test and control, while the factor time's two levels were baseline (t_0) and three months (t_1). A one-way repeated-measures ANOVA for dependent samples, was conducted to assess whether there were differences in the mean HU in the test group as compared to the control group at three months. Hypothesis testing was carried out pertaining to the statistical test of choice.

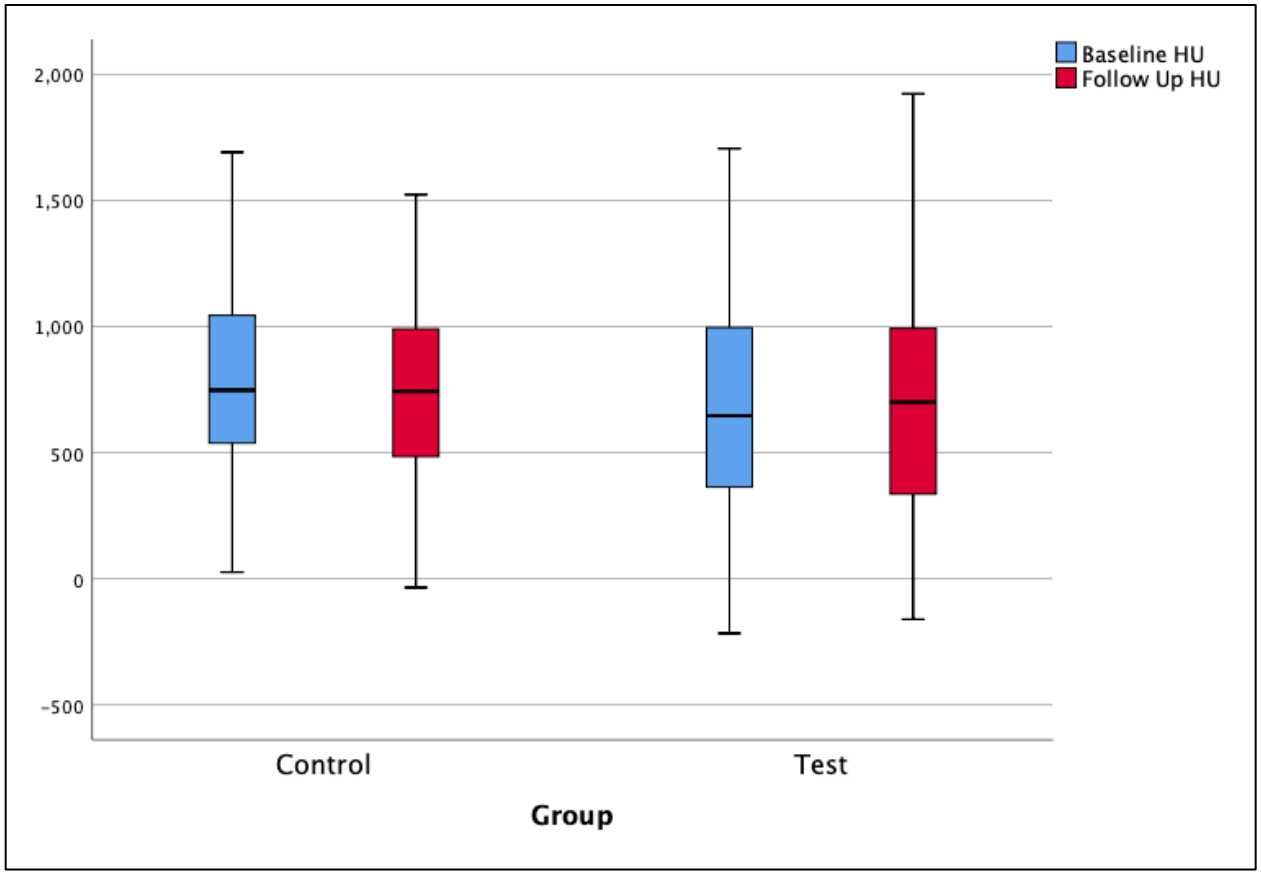


Figure 12: Boxplot depicting distribution of the Hounsfield unit (HU) values for test and control group (n=397)

Using the main outcome variable HU, the distribution of the data was visually assessed with a boxplot. Figure 12 depicts that the sample was normally distributed. The box plot indicates that the spread of the HU for both the control and the test groups at baseline (t_0) and at three months (t_1). The confidence interval (CI) for the mean HU in the control group at baseline (t_0) was 783.29 ± 336.25 with a 95% CI [730.21, 836.37], and at three months (t_1), it was 731.79 ± 332.16 with a 95% CI [678.87, 784.70]. The confidence interval (CI) for the mean HU in the test group at baseline (t_0) was 672.77 ± 438.34 with a 95% CI [617.36, 7728.18], and at three months (t_1), it was 688.78 ± 439.51 with a 95% CI [633.55, 744.01]. See Appendix J for the descriptive summaries.

Test of Within-subjects effects

The test of within-subjects effects results indicated a significant difference in the mean HU at baseline (t_0) and at three months (t_1). The Greenhouse-Geisser test statistic was as follows: [F(df=1)=3.965, p=0.047]. The results of the pairwise comparison of the mean HU using the least significant difference (LSD post-hoc test) between the baseline (t_0) and three months (t_1) revealed that the difference in the mean HU was 17.746 (p=0.047) with a 95% CI [0.225, 35.267].

Test of Between-subjects effects

The test of between-subjects effects results indicated a significant difference in the mean HU between the test group and the control group. The associated test statistic was as follows: [F(df=1)=4.095, p=0.044]. The results of the pairwise comparison of the mean HU using the least significant difference (LSD post-hoc test) between the control and the test group revealed that the difference in the mean HU value was 76.765 (p=0.044) with a 95% CI [2.184, 151.345].

Test for Interaction between factors

The test for interaction results indicated a significant interaction between the two factors: group and time. The associated Greenhouse-Geisser test statistic was as follows: [F(df=1)=0.14.438, p<0.0001]. The results of the pairwise comparison of the mean HU using the least significant difference (LSD post-hoc test) between the control group and the test group at baseline (t_0) revealed that the mean difference in the HU value was 110.52 (p=0.005) with a 95% CI [33.791, 187.251]. The results of the pairwise comparison of the mean HU using the least significant difference (LSD post-hoc test) between the control group and the test group at three months (t_1) revealed that the mean difference in the HU value was 43.008 (p=0.270) with a 95% CI [-33.484, 119.500].

3.5.4 Interpretation of the Results for the HU Value for the Entire Data Set (n=397)

The statistical analysis concluded that the overall mean BMD in the entire data set (combining test and control group teeth together) decreased by 17.746 HU at the end of three months. A pairwise comparison was done between the mean HU values of the teeth at baseline (t_0) and at three months (t_1) in the test group. The HU value at three months (t_1) was 16.011 units (p=0.214) higher than the value at baseline (t_0), but was statistically not significant (Appendix J).

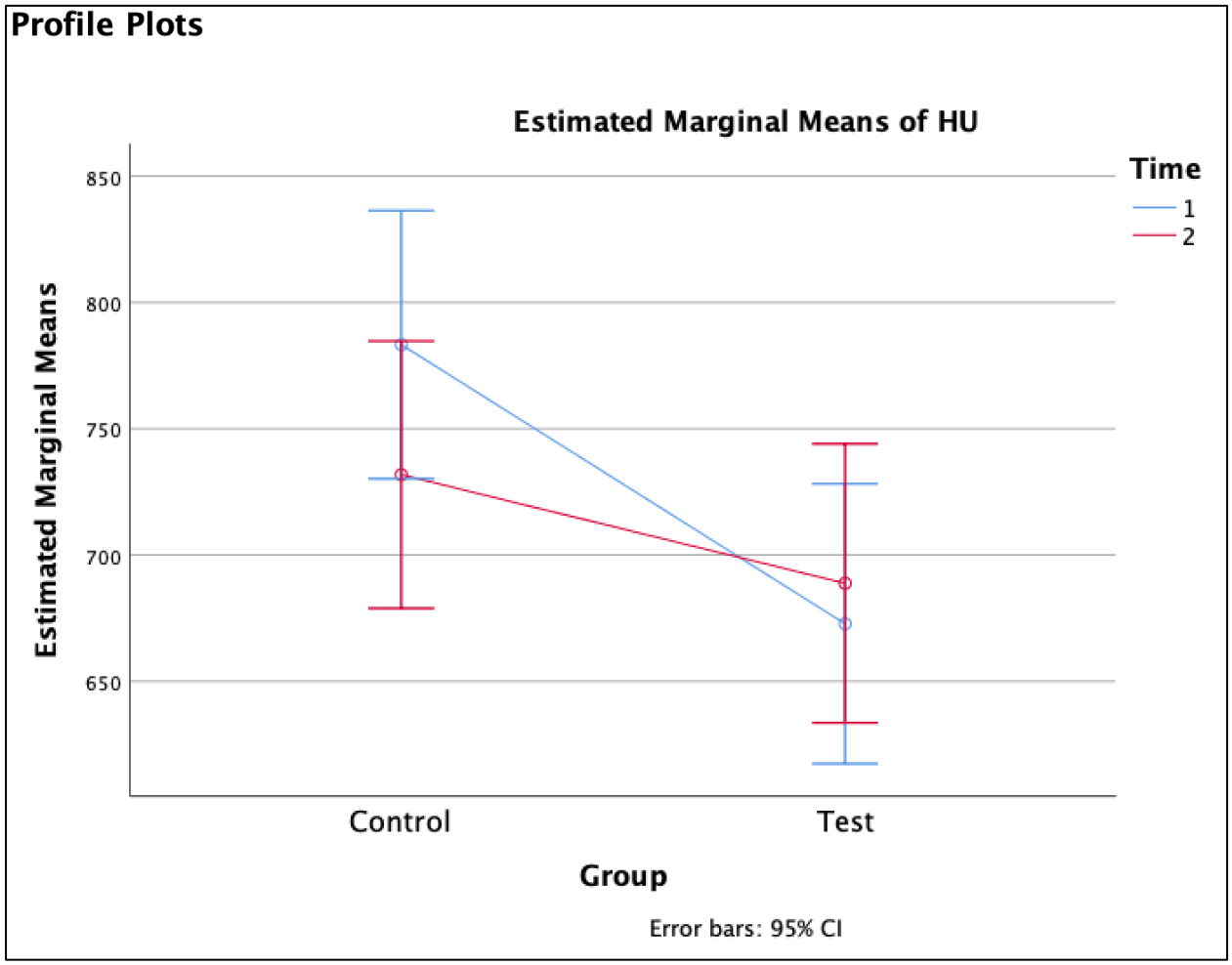


Figure 13: Profile plot depicting estimated marginal means of Hounsfield units (HU) for the test and control group (n=397)

The evidence provided by the data supports that use of HFV via the PTech device for 12 weeks did not show a statistically significant change in the mean HU of teeth at baseline (t_0) and at

three months (t_1) in the test group. These results are further elaborated in the visual representation in Figure 13.

The profile plot in Figure 13 depicts the estimated marginal means of both the control group and the test group at baseline (t_0) (blue in colour) and at three months (t_1) (red in colour). Group (test versus control) is depicted on the x-axis. The y-axis represents the mean BMD measured in HU. In both the test group and the control group, the confidence interval of the mean HU at baseline (t_0) (blue in colour and numeral 1) and at three months (t_1) (red in colour and numeral 2) overlap. The lines connecting the estimate of marginal means (red line and blue line) cross-over, meaning that both the individual groups and different times interact, and their mean HU differ. Despite the overlap in the confidence intervals shown in the profile plot in Figure 13 based on the tests statistic and the associated p-value mentioned above, we conclude that the mean HU in the test group and the control group differ significantly at all times.

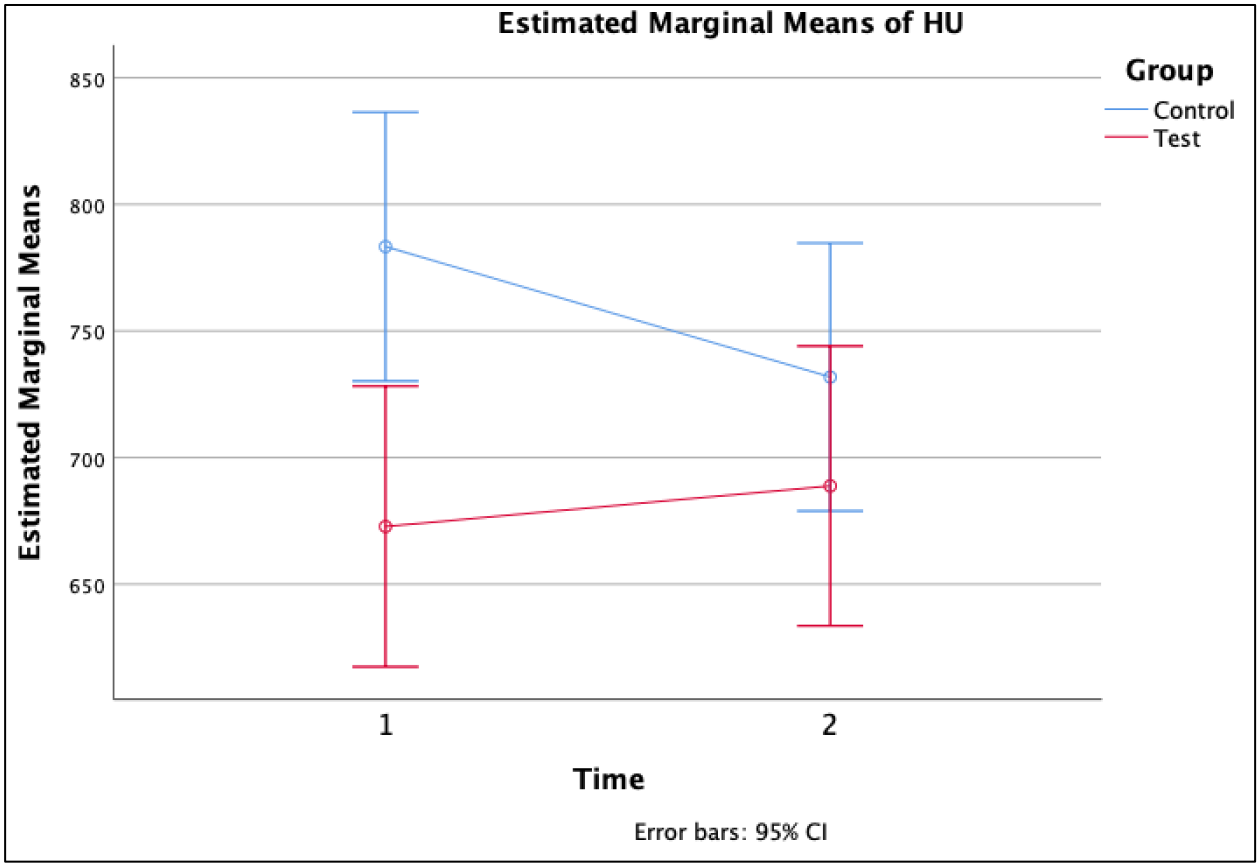


Figure 14: Profile plot depicting estimated marginal means of Hounsfield units (HU) at time: baseline (1) and three months (2); (n=397)

The profile plot in Figure 14 depicts the estimated marginal means at baseline (t_0) and at three months (t_1) of both the test group and the control group. Time is depicted on the x-axis, indicating baseline (t_0 – numeral 1) and at three months (t_1 – numeral 2). The y-axis represents the mean BMD measured in HU. Notably, the mean HU value increased in the test group and decreased in the control group from baseline (t_0) to three months (t_1). At baseline (t_0 – numeral 1) the confidence interval of the test group and the control group do not overlap, indicating that the HU means for both groups differ at baseline (t_0). The higher mean HU of the control group was evident from the profile plot due to the corresponding value of the mean HU on the y-axis.

The mean HU difference between the control group and the test group at baseline (t_0 – numeral 1) was 110.521 HU (p=0.005) with a 95% CI [33.791, 187.251]. Notably, by the process of randomization, the research participants who were allocated to the control group, to begin with, had slightly higher BMD as measured in HU. At three months (t_1 – numeral 2), the confidence interval of the test group and the control group overlap, indicating that the mean HU was same for both. Although the numerical value of the mean difference was 43.008 HU (p=0.270) with a 95% CI [-33.484, 119.50] between the control group and the test group. This difference was not statistically significant as evidenced by the statistic mentioned above and its associated p-value. The mean HU of the test group had increased, and the mean HU of the control group had decreased, as evident from the profile plot due to the corresponding value of the mean HU on the y-axis. This was consistent with the results of the pairwise comparison of the mean HU using the least significant difference (Appendix J).

This concludes the section of results for the entire data set, which meant data points on all the available teeth in the 17 patients.

The subsequent section will focus on the data analysis on the target teeth (mobile teeth). The following headings will detail about the data analysis being conducted and their individual results accordingly.

3.6 Data Transformation for target teeth (mobile teeth)

The digitized data was further transformed using Microsoft Excel version 16.60. Target teeth that were identified as mobile in the last annual periodontal recall examination were isolated form the entire data set that consisted of 423 teeth in all the 17 patients. A total of 116 target teeth were identified. Of 116 teeth, two teeth were identified as missing the Periotest value (PTV) and therefore

were removed from the analysis. Therefore, a total 114 target teeth were available with PTV values at baseline (t_0) and at three months (t_1). Amongst these 114 target teeth, 59 teeth belonged to the test group and 55 teeth belonged to the control group. Statistical analyses for PTV was conducted on measurements taken on all these 114 teeth. They were arranged in Microsoft Excel with each tooth occupying an independent row and subsequent columns had the PTV at baseline (t_0) and three months (t_1). The third column consisted of the identification from the test group versus the control group (Appendix I).

Similar transformation was done for the BMD calculated in HU. In total 110 teeth were available for HU values at baseline (t_0) and three months (t_1). Amongst these 110 target teeth 59 belonged to the test group and 51 teeth belonged to the control group. While determining the HU values from the CBCT, teeth which were adjacent to dental implants, root canal treated teeth and other restorative material that caused a lot of scatter were removed as it made calculation of the HU very challenging. Therefore, HU were measured only on 110 teeth and not entire 116 target teeth. Statistical analysis for HU were conducted on measurements taken on all these 110 teeth. See Appendix I for visual representation of the data transformation explained above both for the PTV and HU.

3.7 Data Analysis for target teeth (mobile teeth, n =114)

3.7.1 Data Analysis for the Periotest Value for Target Teeth (mobile teeth, n =114)

The transformed data was imported into IBM SPSS software version 26. The outcome variable measured was the Periotest value (PTV). Two factors responsible for affecting the outcome variable were identified as time and group; each with two levels. The factor “group” had two levels

– test and control. Similarly, the factor "time" had two levels – baseline (t_0) and three months (t_1). A one way repeated-measures ANOVA for dependent samples, was conducted to assess whether there were differences in the mean PTV in the test group as compared to the PTV in the control group. Hypothesis testing was carried out pertaining to the statistical test of choice.

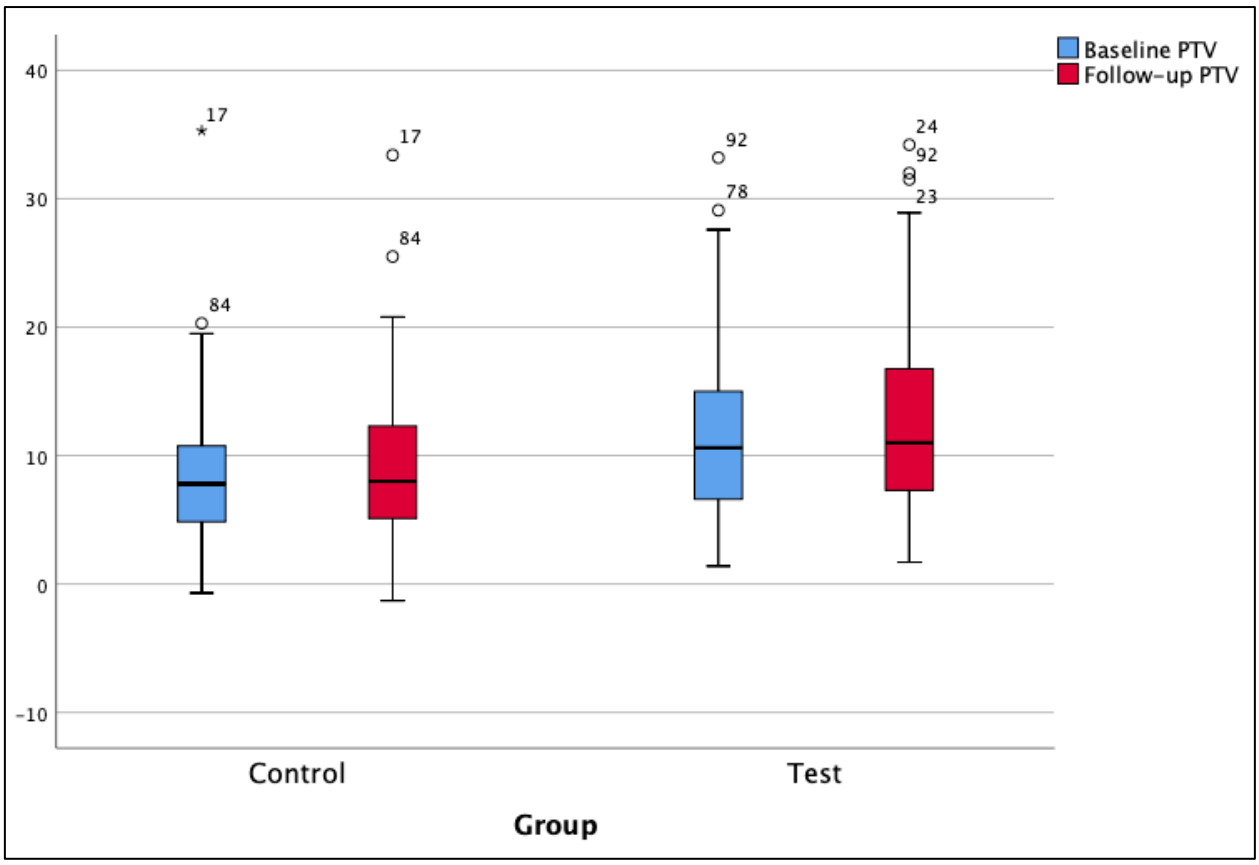


Figure 15: Boxplot depicting distribution of the Periotest values (PTV) for test and control group (n=114)

Using the main outcome variable PTV, the distribution of the data was visually assessed with a boxplot. Figure 15 depicts that the sample was normally distributed. The box plot indicates that the spread of the PTV for both the control and the test groups at baseline (t_0) and at three months (t_1). The confidence interval (CI) for the mean PTV in the control group at baseline (t_0) was 8.890 ± 0.938 with a 95% CI [7.122, 10.838], and at three months (t_1), it was 8.953 ± 0.971 with a 95% CI [7.029, 10.877]. The confidence interval (CI) for the mean PTV in the test group at baseline (t_0) was 11.861 ± 0.905

with a 95% CI [10.067, 13.655], and at three months (t_1), it was 12.990 ± 0.938 with a 95% CI [11.132, 14.848].

Notably, by the process of randomization the research participants who were allocated to the test group had higher PTV to begin with as compared to the control group. This means that considering the PTV scale of -8 to +9, the control group target teeth on an average had Miller's physiological mobility and considering the PTV scale of +10 to +19 the test group target teeth on an average had Miller's grade 1 mobility. The detailed descriptive summaries and associated output generated from IBM SPSS software version 26 can be seen in Appendix K.

Test of Within-subjects effects

The test of within-subjects effects results indicated no significant difference in the mean PTV at baseline (t_0) and at three months (t_1). The Greenhouse-Geisser test statistic was as follows: [F(df=1)=1.920, p=0.169].

Test of Between-subjects effects

The test of between-subjects effects results indicated a significant difference in the mean PTV between the test and the control group. The associated test statistic was as follows: [F(df=1)=7.466, p=0.007]. The results of the pairwise comparison using the least significant difference (LSD post-hoc test) between the test and the control group revealed a mean difference in the PTV value of 3.459 (p=0.007) with a 95% CI [0.951, 5.967].

Test for Interaction between factors

The test for interaction results indicated no interaction between group and time. The associated Greenhouse-Geisser test statistic was as follows: [F(df=1)=2.115, p=0.149], indicating that the differences in mean PTV between test and control were the same.

3.7.2 Interpretation of the Results for the Periotest Value for Target Teeth (mobile teeth, n =114)

The evidence provided by the data supports that there was no difference in the PTV value of teeth at baseline (t_0) and at three months (t_1). The use of HFV via the PTech device for 12 weeks did not change the PTV in either the test group or the control group. It is to be noted that the mean PTV increased in the test group and slightly decreased in the control groups from baseline (t_0) to three months (t_1), but the change was not statistically significant. These results are further elaborated based on the visual representation in Figure16 below.

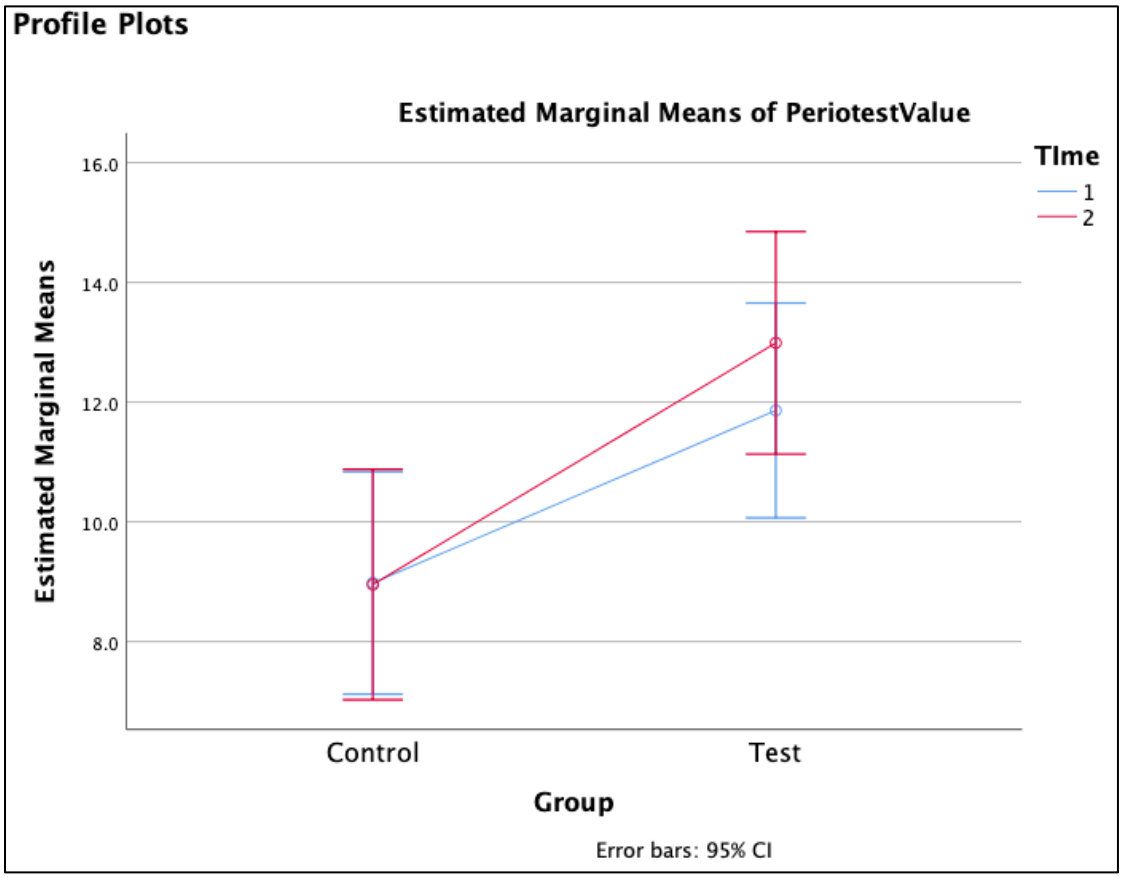


Figure 16: Profile plot depicting estimated marginal means of Periotest value (PTV) for the test and control group (n=114)

The profile plot in Figure 16 depicts the estimated marginal means of both the test group and the control group at baseline (t_0) (blue in colour) and at three months (t_1) (red in colour). The group (test versus control) is depicted on the x-axis. The y-axis represents the mean PTV. In both the test group and the control group, the confidence interval of the mean PTV at baseline (t_0) (blue in colour and numeral 1) and at three months (t_1) (red in colour and numeral 2) overlap, indicating that the mean PTV are same in both the groups at baseline (t_0) and at three months (t_1). This result corresponds with the calculated test statistic and the associated p-value for the test of within-subjects effects. The Greenhouse-Geisser test statistic was as follows: [F(df=1)=1.920, p=0.169]. Notably, by the process of randomization the research participants who were allocated to the test group had higher PTV to begin with as compared to the control group. The mean difference in the PTV value between the test group and the control group was 3.459 (p=0.007), but this numerical difference in PTV was noted above and explained that by the process of randomization the research participants who were allocated to the test group had higher PTV to begin with as compared to the control group.

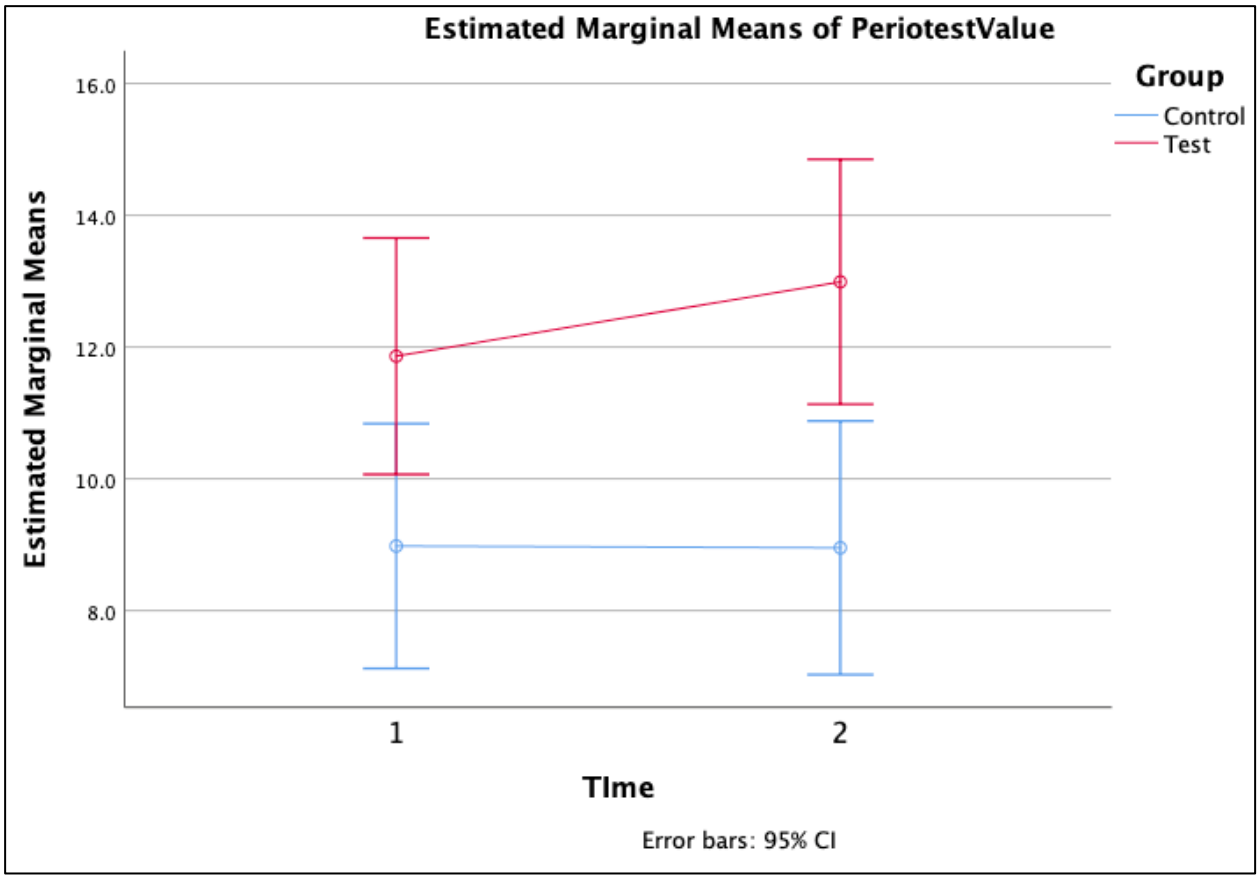


Figure 17: Profile plot depicting estimated marginal means of Periotest value (PTV) at time: baseline (1) and three months (2); (n=114)

The profile plot in Figure *17* depicts the estimated marginal means at baseline (t_0) and at three months (t_1) of both the test group (red in colour) and the control group (blue in colour). Time is depicted on the x-axis. The numeral 1 represents the baseline (t_0) and the numeral 2 represents the three months (t_1). The y-axis represents the PTV. At baseline (t_0) (i.e., time 1), the confidence interval (CI) of the test group and the control group overlap. Despite the overlap in the confidence intervals shown in the profile plot above based on the tests statistic the mean difference in the test group and the control group at baseline (t_0) was 2.881 ($p=0.029$). With the associated p-value mentioned above we conclude that the mean PTV in the test group and the control group are significantly different at baseline (t_0).

The higher mean PTV of the test group is evident from the profile plot due to corresponding value of mean PTV on the y-axis. At three months (t_1) (i.e., time 2), the confidence interval of the test and the control group do not overlap indicating that the mean PTV differ in both groups at three months (t_1). The mean difference in the test group and the control group at three months (t_1) was 4.037 ($p=0.003$) and therefore we conclude that the mean PTV in the test group and the control group are significantly different at three months (t_1). The higher mean PTV of the test group is evident from the profile plot due to corresponding value of mean PTV on the y-axis. Though we see these differences in the test group and the control group individually, the overall result of the one way repeated-measures ANOVA for dependent samples in not significant for time, indicating that statistically the mean PTV at baseline (t_0) and at three months (t_1) are same. This corresponds to the calculated test statistic and the associated p-value as follows: Greenhouse-Geisser test statistic [$F(df=1)=1.920$, $p=0.169$].

3.7.3 Data Analysis for the Bone Mineral Density in Hounsfield units (HU) for the Target Teeth (mobile teeth, n=110)

The transformed data was imported into IBM SPSS software version 26. The outcome variable measured was the BMD measured in Hounsfield units (HU). In total, 110 teeth were available for HU values at baseline (t_0) and at three months (t_1). The two factors affecting the outcome variable were time and group, each with two levels. The factor group's two levels were test and control, while the factor time's two levels were baseline (t_0) and three months (t_1). A one-way repeated-measures ANOVA for dependent samples, was conducted to assess whether there were differences in the mean HU in the test group as compared to the control group at three months. Hypothesis testing was carried out pertaining to the statistical test of choice.

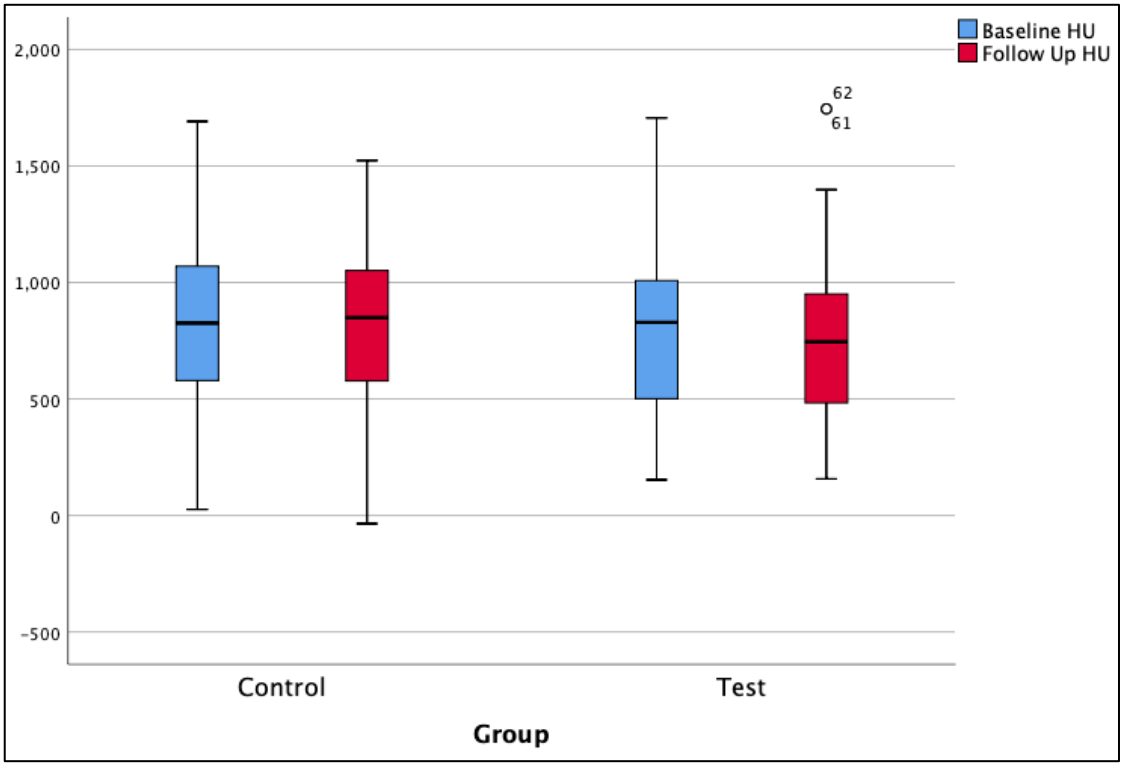


Figure 18: Boxplot depicting distribution of the Hounsfield unit (HU) values for test and control group (n=110)

Using the main outcome variable HU, the distribution of the data was visually assessed with a boxplot. Figure 18 depicts that the sample was normally distributed. The box plot indicates that the spread of the HU for both the control and the test groups at baseline (t_0) and at three months (t_1). The confidence interval (CI) for the mean HU in the control group at baseline (t_0) was 825.745 ± 51.782 with a 95% CI [723.105, 928.385], and at three months (t_1), it was 808.353 ± 50.864 with a 95% CI [707.532, 909.174]. The confidence interval (CI) for the mean HU in the test group at baseline (t_0) was 789.881 ± 48.143 with a 95% CI [694.453, 885.309], and at three months (t_1), it was 769.678 ± 47.290 with a 95% CI [675.941, 863.415].

Notably, by the process of randomization the research participants who were allocated to the control group had higher mean HU to begin with as compared to the test group. The detailed

descriptive summaries and associated output generated from IBM SPSS software version 26 can be seen in Appendix K.

Test of Within-subjects effects

The test of within-subjects effects results indicated there was no significant difference in the mean HU at baseline (t_0) and three months (t_1). The Greenhouse-Geisser test statistic was as follows: [F(df=1)=1.422, p=0.236].

Test of Between-subjects effects

The test of between-subjects effects results indicated there was no significant difference in the mean HU between the test and the control group. The associated test statistic was as follows: [F(df=1)=0.298, p=0.586].

Test for Interaction between factors

The test for interaction results indicated that there was no interaction between the two factors: group and time. The associated Greenhouse-Geisser test statistic was as follows [F(df=1)=0.008, p=0.929], indicating that the differences in mean HU between test and control were the same.

3.7.4 Interpretation of the Results for the Bone Mineral density in Hounsfield units (HU) for the Target Teeth (mobile teeth, n= 110)

The evidence provided by the data supports that there was no difference in the mean HU value of teeth at baseline (t_0) and at three months (t_1). The use of HFV via the PTech device for 12 weeks does not change the BMD as measured in the HU in either the test group or the control group. Notably, the numerical value of mean Hounsfield units (HU) has slightly decreased in both the control and the test groups from baseline (t_0) to three months (t_1) but the change was not statistically

significant. These results are further elaborated based on the visual representation in Figure 19 below.

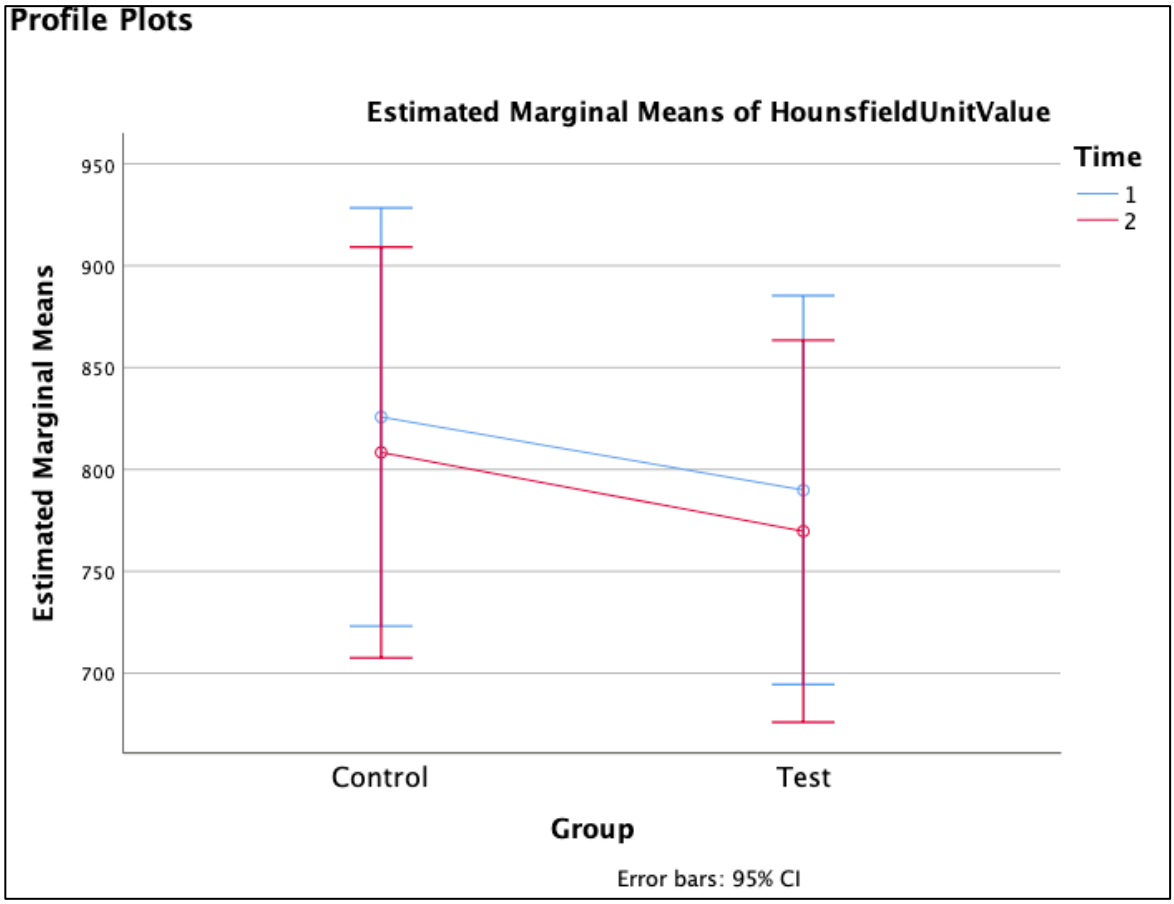


Figure 19: Profile plot depicting estimated marginal means of Hounsfield units (HU) for the test group and control group (n=110)

The profile plot in Figure 19 depicts the estimated marginal means of both the control group and the test group at baseline (t_0) (blue in colour) and at three months (t_1) (red in colour). Group (test versus control) is depicted on the x-axis. The y-axis represents the mean BMD measured in HU. In both the test group and the control group, the CI of the mean HU at baseline (t_0) (blue in colour and numeral 1) and at three months (t_1) (red in colour and numeral 2) overlap. The overlap indicated that the mean HU in the control group and the mean HU in the test group was same at baseline (t_0), and at three months (t_1).

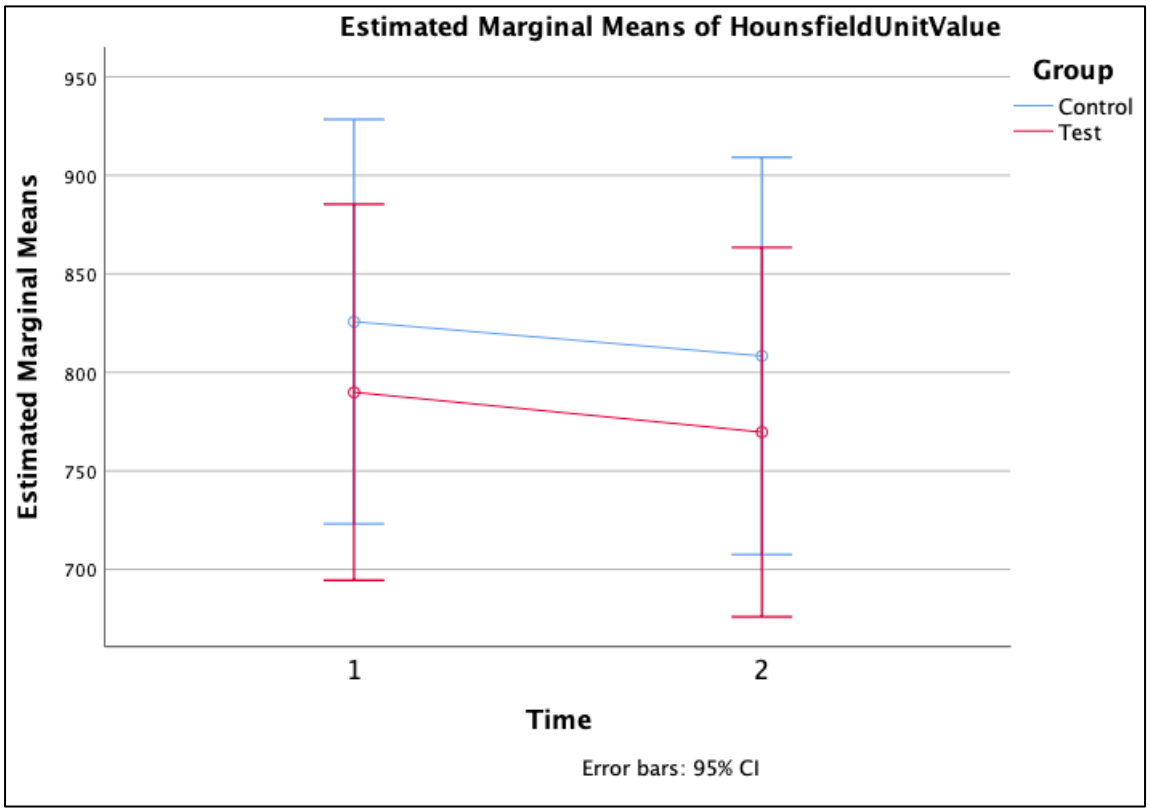


Figure 20: Profile plot depicting estimated marginal means of Hounsfield nits (HU) at time: baseline (1) and at three months (2); (n=110)

The profile plot in Figure 20 depicts the estimated marginal means at baseline (t_0) and at three months (t_1) of both the test group (red in colour) and the control group (blue in colour). Time is depicted on the x-axis, indicating baseline (t_0 – numeral 1) and three months (t_1 – numeral 2). The y-axis represents the BMD measured in HU. Notably, the numerical value of mean HU has slightly decreased in both the control group and the test group from baseline (t_0) to three months (t_1). At baseline (t_0 – numeral 1) and at three months (t_1 – numeral 2) the confidence interval of the test and the control group overlap indicating that the mean HU was same in both groups. The higher mean HU of the control group is evident from the profile plot due to corresponding value of mean HU on the y-axis.

The mean HU difference between the control group and the test group at baseline (t_0 – numeral 1) was 35.864 HU (p=0.613) with a 95% CI [-104.284, 176.012]. Notably, by the process of randomization the research participants who were allocated to the control group had slightly higher BMD as measured in HU. At three months (t_1 – numeral 2), the mean HU difference between the control group and the test group was 38.675 HU (p=0.579) with a 95% CI [-98.989, 176.339]. At both baseline and at three months these differences are not statistically significant as indicated by the statistic mentioned above and its associated p-value. This was consistent to the output generated from IBM SPSS software version 26 and can be seen in Appendix K.

.

4. Discussion

The goal of this research project was to conduct a pilot randomized clinical trial and to study the effects of High-Frequency Vibration (HFV) on the periodontium in a clinical setting. The measurable outcomes were changes in clinical tooth mobility as shown by the Periotest value (PTV) and any change in bone mineral density (BMD) as measured in Hounsfield units (HU). The unit of measurement was the tooth, and the measurements (both PTV and HU) of the same tooth were made during the baseline examination and a subsequent examination at three months.

The HFV was delivered to the test participants by using the PTech device for five minutes every night for 12 weeks. From the statistical analyses (both the entire data set and the target teeth) shown in the previous section, it can be concluded that there was no change in the clinical tooth mobility (as measured by the PTV) at the end of the three months. These results were also corroborated by carefully observing any change in the tooth mobility using Miller's method based on the clinical exam, recording all periodontal indices at the baseline and at three months. There was no meaningful change observed in the clinical tooth mobility using Miller's method in either the control group or test group at the end of three months. For an example, a tooth that was identified as having Miller's grade 2 mobility was found to have the same mobility at the end of three months, and, similarly, a tooth that was identified as having Miller's grade 1 mobility was found to have the same mobility at the end of three months. Even though the PTV of these teeth varied numerically, the change was not statistically significant. The findings based on the PTV (i.e., no change before and after) are endorsed by the Miller's method of detecting clinical mobility (i.e., no change before and after).

The other outcome variable measured was the change in the BMD as measured in HU. Based on our hypothesis testing, we addressed the following question: Does delivery of HFV to the test participants by using the PTech device for five minutes every night for 12 weeks change BMD around the teeth? From the statistical analyses shown in the previous section, at three months, there was a statistically non-significant increase in BMD [16.11 HU (p=0.214)] in the test group and therefore it can be hypothesized that with more time the change in BMD might have been significant.

When considering the entire data set, that includes control and the test teeth (n=397 teeth) we concluded that the BMD around the teeth decreased by 17.76 HU. This appears to be controversial because when a subset analysis was done to see the effect of HFV on the teeth in the test group at t_0 and t_1, we deduced a numerical increase in BMD of 16.011 HU, though this was statistically not significant change as mentioned above. The control group received a sham device and therefore a change in BMD in terms of HU is not expected. The only meaningful explanation of a decrease of BMD in the entire data set (all teeth) by 17.76 HU is measurement error by the graduate student. Furthermore, no clinically visible change or impact was detected.

In a clinical study on peri-menopausal women, regression analysis depicted a weak association between the skeletal BMD and tooth mobility as measured by PTV (Singh, Sharma, Tewari, & Narula, 2012). It can be reasoned that the improvement in BMD around the teeth will eventually reduce tooth mobility by strengthening the foundation.

When considering the target teeth i.e., mobile teeth only (n=110 teeth), from the statistical analyses shown in the previous section, we concluded that there was no change in the BMD around the mobile teeth at the end of the three months. Notably, the majority of the teeth (72%) in the entire data set (n=397) on which BMD was determined using HU were not mobile

at the baseline. It can be hypothesized that stimulating bone formation around loose teeth (mobile teeth) will take longer as compared to teeth that are not mobile to begin with.

For many reasons, our results differ from the promising results shown in the orthodontic literature on the use of the HFV device. The goal for using HFV in orthodontics is to move teeth faster and hence reduce the orthodontic treatment time. The movement of teeth under pressure of orthodontic forces is a catabolic activity on the periodontium (Farouk, Shipley, & El-Bialy, 2018). The breakdown of periodontal ligament (PDL) and the surrounding bone under the influence of the orthodontic forces stimulates the entire cascade of bone remodelling. On the pressure side, the catabolic activity is accelerated due to HFV, the bone is dissolved rapidly, and the teeth move faster. On the non-pressure side, the bone is being deposited or regenerated faster due to supplemental HFV in comparison to orthodontics without HFV therapy (Alikhani, et al., 2018). Therefore, stimulus in the form of orthodontic forces, along with the HFV, produces a profound effect that can be clinically measured in terms of reduced orthodontic treatment time. In this pilot study, the only stimulus applied to the test group participants was HFV delivered by the PTech device, and that, in itself, may take longer than three months to show an effect with a clinically measurable change.

Another observable difference from the previous orthodontic studies was the duration of the use of HFV using the PTech device. Studies in the orthodontic literature that show a meaningful change in the treatment outcomes with the HFV device have used it for at least 12 – 18 months, along with active orthodontic forces (Shipley, Farouk, & El-Bialy, 2019). In our study, participants used the PTech device for only 12 weeks, which is not enough to achieve bone remodelling and see its effects clinically. Since this study was the first of its kind in the field of periodontology, we used a conservative approach, and therefore the device was used for

five minutes per day for only 12 weeks to monitor and report on any unwanted effects. No adverse outcomes of the HFV therapy were reported by the patients. Nor do the data support any ill effects of HFV on the periodontal patients. Future studies can be safely commenced by extending the research time from six months to a year to study the effects of HFV on the periodontium.

The study had several limitations. First, the sample was not an independent sample as the unit of measurement was teeth on which data was collected along with data on adjacent teeth and the teeth in the opposing arch. There is no practical way to isolate only mobile teeth and study them individually. The PTech device simultaneously touches all the teeth in the arch when the patient is occluding and holding the device between the maxillary and mandibular arches. Therefore, to study the effects of HFV on the periodontium, data was collected on all the teeth rather than mobile teeth only.

Second, the patients were asked to use a mobile app that connected the PTech device to their smart phone, in order to track and document their compliance in using the device for five minutes per night for 12 weeks. However, only the PTech devices for the test group participants would connect to the Android or iOS mobile app. One participant in the test group tried to use the app but was unsuccessful. Therefore, all the patients submitted a paper-based log of their use of the PTech device. Although the compliance on the use of the HFV device on the paper-based log was above 95%, one cannot ignore the possibility of bias, as patients may have reported using the device more than they actually did. In the orthodontic studies the mean age of the patients was around 25 years, and all of them used the mobile app; therefore, the compliance data in these studies could be directly monitored by the principal investigator.

Another limitation of the study was that it was impossible to determine if differences in the tooth mobility were caused by attachment loss or reduced BMD around the tooth. The clinically detectable mobility around the teeth cannot be differentiated by its cause (attachment loss or reduced BMD) and their effects studied separately. Therefore, the results of this study on the change in BMD in the test group and the hypothesis that increased BMD reduces clinical mobility around teeth should be interpreted with caution.

The only method available in the school setting to measure the bone density was CBCT. However, in the field of radiology, there has been some debate about limitations in regular CBCT for measuring bone density and specifically using the Hounsfield units generated by CBCT (Eguren, et al., 2022). In actual radiology centres, the Hounsfield units are derived from the multidetector CT (MDCT) data. The gray values in the CBCT show great variability due to, among other factors, the limited field size, relatively high amount of scattered radiation, and limitations of currently applied reconstruction algorithms (Pauwels, Jacobs, Singer, & Mupparapu, 2015). Having said that, the latest update on the software Anatomage version 6.0 provided means to calculate the Hounsfield units. Since we used the same parameters (0.3 mm voxel size, 8 cm X 8 cm (maxilla and mandible included) and 8.9 seconds of exposure time), repeated measurements on the same patient, and used the same RDA technician for CBCT acquisition, the sources of error were reduced. Considering the possible source of error in the calculation of Hounsfield units from the CBCT, it can be inferred that the error was the same for both calculating the Hounsfield units at baseline and at three months. In essence, the data showed us the change in BMD. Although this change may not have been precise, it helped us to hypothesize further studies.

The sample size of 17 patients is small and is a limitation of the study. Of these 17 patients, nine were in the control group and eight in the test group. The recruitment of research participants was severely impacted by the Covid-19 pandemic. Patients in general were hesitant to come to the dental school for treatment unless absolutely necessary. A general trend was observed of reduced patients in the undergraduate DDS dental clinic, the Dental Hygiene Program, and the Graduate Periodontology Program. Patients contacted over the phone expressed to the treatment coordinator or the graduate student that, although the research participation opportunity sounded promising, they would likely not participate. The consent form that was developed for the study and approved by the research and ethics board may also have deterred some patients, as it mentioned an increased risk of exposure to Covid-19 at the Graduate Periodontology Clinic.

Future studies should be done post-pandemic (Covid-19) when the flow of the patient pool in the dental school and especially in the Graduate Periodontology Clinic is normal, and more patients are willing to participate in the research project. Secured funding should be procured, and the resources should be properly allocated. A dental hygienist should be added to the research team to reduce the graduate student's workload and to provide maintenance therapy to the research participants. Being able to offer maintenance therapy would help to recruit a larger patient pool and to collect longitudinal data at three months, six months, and up to 12 months on changes of HFV on clinical tooth mobility and BMD. This pilot study was done on a small scale in a dental school setting. Future studies can consider recruiting a similar patient pool in another Graduate Periodontology Program in Canada or the USA. Considerations should be made to collect data at private practice periodontal clinics where more regular care is sought by

periodontally aware patients and data collection would be easy due to a more productive practice style.

To secure more accurate data on BMD, the CBCT acquisition parameters should be more robust in future studies. The CBCT parameters used in this pilot trial were of low resolution (0.3 mm voxel size, 8 cm X 8 cm (maxilla and mandible included) and 8.9 seconds exposure time). Perhaps a high-resolution scan would provide more comprehensive information about BMD and help identify any change in angular bone defect anatomy due to bone formation, if any.

5. Conclusion

This pilot randomized clinical trial was the first study of its kind in the field of periodontology to study the effects of High Frequency Vibration (HFV) on the periodontium in a clinical graduate program setting. Research participants were randomly allocated to the test group or the control group. The test group participants received HFV through the PTech device for five minutes per night for 12 weeks. Similar data were collected at baseline and at three months by the same provider. At the end of the study, when considering mobile teeth (target teeth, n=116) we concluded that there was no evidence of change in the clinical tooth mobility, neither shown by the Periotest value (PTV) nor by Miller's method. Similarly, there was no statistically significant change in the bone mineral density (BMD) measured in terms of Hounsfield Units (HU) determined from the CBCT. Future studies on a larger scale are needed to validate and extrapolate the results of this pilot study.

References

Alansari, S., Atique, M. I., Gomez, J. P., Hamidaddin, M., Thirumoorthy, S. N., Sangsuwon, C., . . . Nervina, J. M. (2018). The effects of brief daily vibration on clear aligner orthodontic treatment. *Journal of the World Federation of Orthodontists, 7*(4), 134--140.

Alikhani, M., Alansari, S., Hamidaddin, M. A., Sangsuwon, C., Alyami, B., Thirumoorthy, S. N., . . . Teixeira, C. C. (2018). Vibration paradox in orthodontics: Anabolic and catabolic effects. *PLoS One, 13*(5), e0196540.

Alikhani, M., Alikhani, M., Alansari, S., Almansour, A., Hamidaddin, M. A., Khoo, E., . . . others, a. (2019). Therapeutic effect of localized vibration on alveolar bone of osteoporotic rats. *PLoS One, 14*(1), e0211004.

Bai, K.-H., Hu, C., Li, Q.-Q., & Wang, F. (2019). Effect of low-magnitude high frequency vibration on osteogenic differentiation of human periodontal ligament stem cells. *Shanghai kou qiang yi xue= Shanghai journal of stomatology, 28*(5), 478--483.

Baskan, O., Karadas, O., Mese, G., & Ozcivici, E. (2020). Applicability of low-intensity vibrations as a regulatory factor on stem and progenitor cell populations. *Current Stem Cell Research & Therapy, 15*(5), 391--399.

Benjakul, S., Jitpukdeebodintra, S., & Leethanakul, C. (2018). Effects of low magnitude high frequency mechanical vibration combined with compressive force on human periodontal ligament cells in vitro. *European journal of orthodontics, 40*(4), 356--363.

Billings, M., Holtfreter, B., Papapanou, P. N., Mitnik, G. L., Kocher, T., & Dye, B. A. (2018). Age-dependent distribution of periodontitis in two countries: Findings from NHANES 2009 to 2014 and SHIP-TREND 2008 to 2012. *Journal of clinical periodontology, 45*, S130--S148.

Canada, Health. (n.d.). *Summary report on the findings of the oral health component of the Canadian Health Measures Survey 2007-2009.* Retrieved from Canada.ca: https://www.caphd.ca/sites/default/files/CHMS-E-summ.pdf

Carroll, J. D., Milward, M. R., Cooper, P. R., Hadis, M., & Palin, W. M. (2014). Developments in low level light therapy (LLLT) for dentistry. *Dental Materials, 30*(5), 465--475.

Chakrapani, S., Goutham, M., Krishnamohan, T., Anuparthy, S., Tadiboina, N., & Rambha, S. (2015). Periotest values: Its reproducibility, accuracy, and variability with hormonal influence. *Contemporary Clinical Dentistry, 6*(1), 12.

Chen, D. (2020). Osteogenic potential of periodontal ligament stem cells and immortalized cementoblasts under mechanical vibration forces. *Graduate School, Yonsei University*.

Chow, S.-C., Shao, J., Wang, H., & Lokhnygina, Y. (2017). Sample size calculations in clinical research. *chapman and hall/CRC*.

Doyle, D., Goyal, A., & EH, G. (2022). *American Society of Anesthesiologists Classification*. Retrieved from https://www.ncbi.nlm.nih.gov/books/NBK441940/

Eguren, M., Holguin, A., Diaz, K., Vidalon, J., Linan, C., Pacheco-Pereira, C., & Lagravere Vich, M. O. (2022). Can gray values be converted to Hounsfield units? A systematic review. *Dentomaxillofacial Radiology, 51*(1), 20210140.

Eke, P. I., Dye, B., Wei, L., Thornton-Evans, G., & Genco, R. (2012). Prevalence of periodontitis in adults in the United States: 2009 and 2010. *Journal of dental research, 91*(10), 914--920.

El-Bialy, T., Farouk, K., Carlyle, T. D., Wiltshire, W., Drummond, R., Dumore, T., . . . Tompson, B. (2020). ffect of low intensity pulsed ultrasound (LIPUS) on tooth movement and root resorption: a prospective multi-center randomized controlled trial. *Journal of Clinical Medicine, 9*(3), 804.

Everett, F. G., & Stern, I. B. (1969). When is tooth mobility an indication for extraction? *Dental clinics of North America, 4*, 791--799.

Fan, J., & Caton, J. G. (2018). Occlusal trauma and excessive occlusal forces: Narrative review, case definitions, and diagnostic considerations. *Journal of periodontology, 89*, S214--S222.

Fan, J., & Caton, J. G. (2018). Occlusal trauma and excessive occlusal forces: Narrative review, case definitions, and diagnostic considerations. *Journal of periodontology, 89*, S214--S222.

Farouk, K., Shipley, T., & El-Bialy, T. (2018). Effect of the application of high-frequency mechanical vibration on tooth length concurrent with orthodontic treatment using clear aligners: A retrospective study. *Journal of orthodontic science, 7*.

Fink, D. F., & Smith, R. J. (1992). The duration of orthodontic treatment. *American Journal of Orthodontics and Dentofacial Orthopedics, 102*(1), 45--51.

Friedewald, V. E., Kornman, K. S., Beck, J. D., Genco, R., Goldfine, A., Libby, P., . . . Roberts, W. C. (2009). The American Journal of Cardiology and Journal of Periodontology editors' consensus: periodontitis and atherosclerotic cardiovascular disease. *Journal of periodontology, 80*(7), 1021--1032.

Garman, R., Rubin, C., & Judex, S. (2007). Small oscillatory accelerations, independent of matrix deformations, increase osteoblast activity and enhance bone morphology. *PloS one, 7*(2), e653.

Giargia, M., & Lindhe, J. (1997). Tooth mobility and periodontal disease. *Journal of clinical periodontology, 24*(11), 785–795.

Gilsanz, V., Wren, T. A., Sanchez, M., Dorey, F., Judex, S., & Rubin, C. (2006). Low-level, high-frequency mechanical signals enhance musculoskeletal development of young women with low BMD. *Journal of Bone and Mineral Research, 21*(9).

Herrera, D., Retamal-Valdes, B., Alonso, B., & Feres, M. (2018). Acute periodontal lesions (periodontal abscesses and necrotizing periodontal diseases) and endo-periodontal lesions. *Journal of clinical periodontology, 45*, S78--S94.

Jacobs, R., Salmon, B., Codari, M., Hassan, B., & Bornstein, M. M. (2018). Cone beam computed tomography in implant dentistry: recommendations for clinical use. *BMC Oral Health, 18*(1), 1--16.

Judex, S., Lei, X., Han, D., & Rubin, C. (2007). Low-magnitude mechanical signals that stimulate bone formation in the ovariectomized rat are dependent on the applied frequency but not on the strain magnitude. *Journal of biomechanics, 40*(6), 1333--1339.

Laster, L., Laudenbach, K. W., & Stoller, N. H. (1975). An evaluation of clinical tooth mobility measurements. *Journal of periodontology, 10*, 603--607.

Liedert, A., Kaspar, D., Blakytny, R., Claes, L., & Ignatius, A. (2006). Signal transduction pathways involved in mechanotransduction in bone cells. *Biochemical and biophysical research communications, 349*(1), 1--5.

Ludlow, J., Timothy, R., Walker, C., Hunter, R., Benavides, E., Samuelson, D., & Scheske, M. (2015). Effective dose of dental CBCT—a meta analysis of published data and additional data for nine CBCT units. *Dentomaxillofacial Radiology, 44*(1), 20140197.

Mühlemann, H. (1960). 0 Years of Tooth-Mobility Measurements. *The Journal of Periodontology, 31*, 110-122.

Mah, P., Reeves, T., & McDavid, W. (2010). Deriving Hounsfield units using grey levels in cone beam computed tomography. *Dentomaxillofacial Radiology, 39*(6), 323--335.

Medizintechnik Gulden. (n.d.). *Periotest M operating instructions english.* Retrieved from http://www.med-gulden.com/downloads/02_english/02_Operating%20Manual/Periotest_M.pdf

Miller, S. C. (1950). *Textbook of periodontia: Oral medicine.* Philadelphia: Blakiston.

Muhlemann, H. R. (1967). Tooth mobility: a review of clinical aspects and research findings. *The Journal of Periodontology, 38*(6P2), 686--708.

Muhlemann, H. R., Savdir, S., & Rateitschak, K. H. (1965). Tooth Mobility - Its causes and significance. *The Journal of periodontology, 36*, 148--153.

Murphy, K. G., Wilcko, M. T., Wilcko, W. M., & Ferguson, D. J. (2009). Periodontal accelerated osteogenic orthodontics: a description of the surgical technique. *Journal of Oral and Maxillofacial Surgery, 67*(10), 2160--2166.

Paetyangkul, A., Turk, T., Elekdag-Turk, S., Jones, A. S., Petocz, P., & Darendeliler, M. A. (2009). Physical properties of root cementum: part 14. The amount of root resorption after force application for 12 weeks on maxillary and mandibular premolars: a microcomputed-tomography study. *American Journal of Orthodontics and Dentofacial Orthopedics, 136*(4), 492--e1.

Papapanou, P. N., Sanz, M., Buduneli, N., Dietrich, T., Feres, M., Fine, D. H., . . . Graziani, F. (2018). Periodontitis: Consensus report of workgroup 2 of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. *Journal of periodontology, 89*, S173--S182.

Pauwels, R., Jacobs, R., Singer, S. R., & Mupparapu, M. (2015). CBCT-based bone quality assessment: are Hounsfield units applicable? *Dentomaxillofacial Radiology, 44*(1), 20140238.

Persson, R. (1981). Assessment of tooth mobility using small loads. IV. The effect of periodontal treatment including gingivectomy and flap procedures. *Journal of clinical periodontology, 8*(2), 88--97.

Phusuntornsakul, P., Jitpukdeebodintra, S., Pavasant, P., & Leethanakul, C. (2018). Vibration enhances PGE2, IL-6, and IL-8 expression in compressed hPDL cells via cyclooxygenase pathway. *Journal of periodontology, 89*(9), 1131--1141.

Propel Orthodontics. (n.d.). *VPro™*. Retrieved from Propel Orthodontics VPro™: https://propelorthodontics.com/products/vpro/

Reeves, T., Mah, P., & McDavid, W. (2012). Deriving Hounsfield units using grey levels in cone beam CT: a clinical application. *Dentomaxillofacial radiology, 41*(6), 500--508.

Rios, H. F., Borgnakke, W. S., & Benavides, E. (2017). The use of cone-beam computed tomography in management of patients requiring dental implants: an American Academy of Periodontology best evidence review. *Journal of periodontology, 88*(10), 946--959.

Robling, A. G., Niziolek, P. J., Baldridge, L. A., Condon, K. W., Allen, M. R., Alam, I., . . . others. (2008). Mechanical stimulation of bone in vivo reduces osteocyte expression of Sost/sclerostin. *Journal of Biological Chemistry, 283*(9), 5866--5875.

Rubin, C., Recker, R., Cullen, D., Ryaby, J., McCabe, J., & McLeod, K. (2004). Prevention of postmenopausal bone loss by a low-magnitude, high-frequency mechanical stimuli: a clinical trial assessing compliance, efficacy, and safety. *Journal of Bone and Mineral Research, 19*(3), 343--351.

Schulte, W. a. (1992). Periotest for measuring periodontal characteristics--correlation with periodontal bone loss. *Journal of periodontal research, 27*(3), 184--190.

Schulte, W., & Lukas, D. (1992). The Periotest method. *International dental journal, 42*(6), 433--440.

Schulte, W., d'Hoedt, B., Lukas, D., Maunz, M., & Steppeler, M. (1992). Periotest for measuring periodontal characteristics--correlation with periodontal bone loss. *Journal of periodontal research, 27*(3), 184--190.

Schulte, W., Luka, D., & Ernstt, F. (1990). Periotest values and tooth mobility in periodontal disease: a comparative study. *Quintessence International, 21*(4).

Schulz, K. F., Altman, D. G., & Moher, D. (2010). CONSORT 2010 statement: updated guidelines for reporting parallel group randomised trials. *Journal of Pharmacology and pharmacotherapeutics, 1*(2), 100--107.

Shipley, T. S. (2018). Effects of high frequency acceleration device on aligner treatment - A pilot study. *Dentistry Journal, 6*(3), 32.

Shipley, T., Farouk, K., & El-Bialy, T. (2019). Effect of high-frequency vibration on orthodontic tooth movement and bone density. *Journal of Orthodontic Science, 8*.

Silva, I. M., Freitas, D. Q., Ambrosano, G. M., Boscolo, F. N., & Almeida, S. M. (2012). Bone density: comparative evaluation of Hounsfield units in multislice and cone-beam computed tomography. *Brazilian oral research, 26*(6), 550--556.

Singh, A., Sharma, R. K., Tewari, S., & Narula, S. C. (2012). Correlation of tooth mobility with systemic bone mineral density and periodontal status in Indian women. *Journal of Oral Science, 54*(2), 177--182.

Tonetti, M. S., Greenwell, H., & Kornman, K. S. (2018). Staging and grading of periodontitis: Framework and proposal of a new classification and case definition. *Journal of periodontology, 89*, S159--S172.

Tsichlaki, A., Chin, S. Y., Pandis, N., & Fleming, P. S. (2016). How long does treatment with fixed orthodontic appliances last? A systematic review. *American journal of orthodontics and dentofacial orthopedics, 149*(3), 308--318.

Tyndall, D. A., Price, J. B., Tetradis, S., Ganz, S. D., Hildebolt, C., & Scarfe, W. C. (2012). Position statement of the American Academy of Oral and Maxillofacial Radiology on selection criteria for the use of radiology in dental implantology with emphasis on cone beam computed tomography. *Oral surgery, oral medicine, oral pathology and oral radiology, 113*(6), 817--826.

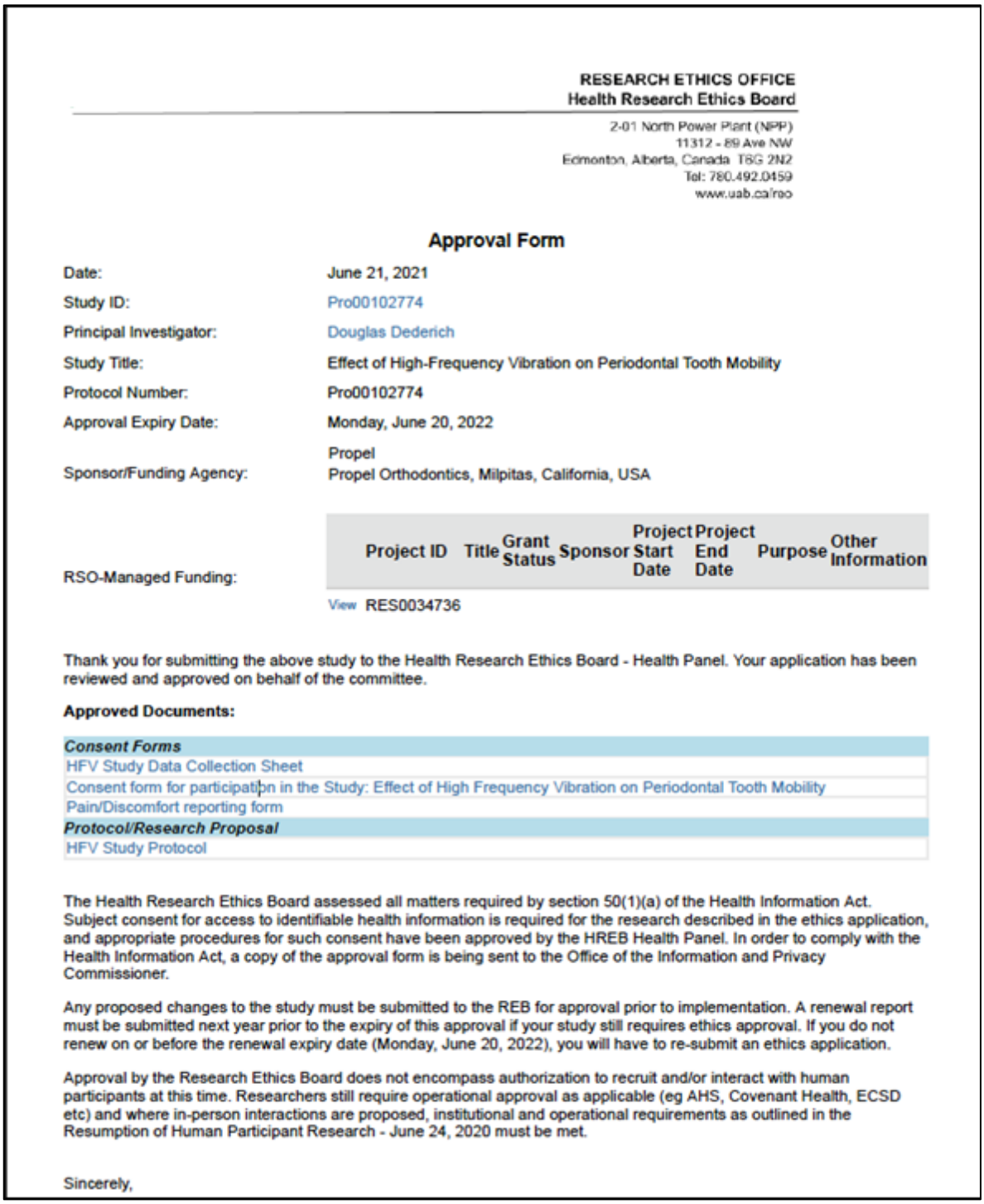
Underbrink, M., Pou, A., Quinn, F., & Ryan, M. (2002). Odontogenic cysts and tumors. *Grand Rounds Presentation, UTMB, Dept of Otolaryngology*.

Varadhan, K. B., Parween, S., Bhavsar, A. K., & Prabhuji, M. L. (2019). Tooth mobility measurements-realities and limitations. *J Evol Med Dent Sci, 8*, 1342--50.

Ward, K., Alsop, C., Caulton, J., Rubin, C., Adams, J., & Mughal, Z. (2004). Low magnitude mechanical loading is osteogenic in children with disabling conditions. *Journal of bone and Mineral Research, 19*(3).

Appendix A

Research ethics board approval of the study:



RESEARCH ETHICS OFFICE
Health Research Ethics Board

2-01 North Power Plant (NPP)
11312 - 89 Ave NW
Edmonton, Alberta, Canada T6G 2N2
Tel: 780.492.0459
www.uab.ca/reo

Approval Form

Date:	June 21, 2021
Study ID:	Pro00102774
Principal Investigator:	Douglas Dederich
Study Title:	Effect of High-Frequency Vibration on Periodontal Tooth Mobility
Protocol Number:	Pro00102774
Approval Expiry Date:	Monday, June 20, 2022
Sponsor/Funding Agency:	Propel Propel Orthodontics, Milpitas, California, USA

RSO-Managed Funding:

Project ID	Title	Grant Status	Sponsor	Project Start Date	Project End Date	Purpose	Other Information
View RES0034736							

Thank you for submitting the above study to the Health Research Ethics Board - Health Panel. Your application has been reviewed and approved on behalf of the committee.

Approved Documents:

Consent Forms
HFV Study Data Collection Sheet
Consent form for participation in the Study: Effect of High Frequency Vibration on Periodontal Tooth Mobility
Pain/Discomfort reporting form
Protocol/Research Proposal
HFV Study Protocol

The Health Research Ethics Board assessed all matters required by section 50(1)(a) of the Health Information Act. Subject consent for access to identifiable health information is required for the research described in the ethics application, and appropriate procedures for such consent have been approved by the HREB Health Panel. In order to comply with the Health Information Act, a copy of the approval form is being sent to the Office of the Information and Privacy Commissioner.

Any proposed changes to the study must be submitted to the REB for approval prior to implementation. A renewal report must be submitted next year prior to the expiry of this approval if your study still requires ethics approval. If you do not renew on or before the renewal expiry date (Monday, June 20, 2022), you will have to re-submit an ethics application.

Approval by the Research Ethics Board does not encompass authorization to recruit and/or interact with human participants at this time. Researchers still require operational approval as applicable (eg AHS, Covenant Health, ECSD etc) and where in-person interactions are proposed, institutional and operational requirements as outlined in the Resumption of Human Participant Research - June 24, 2020 must be met.

Sincerely,

Anthony S. Joyce, PhD.
Chair, Health Research Ethics Board - Health Panel

Note: This correspondence includes an electronic signature (validation and approval via an online system).

Appendix B

Literature review search strategy of databases:

Ovid MEDLINE(R) ALL <1946 to April 22, 2022>

1	exp Periodontics/	26376
2	periodont*.mp.	104697
3	((tooth or teeth) adj5 (move$ or mobility or moving or migrat*)).ti,ab.	7361
4	exp Periodontal Diseases/	92510
5	exp Orthodontics/	54680
6	orthodont*.mp.	62218
7	1 or 2 or 3 or 4 or 5 or 6	199910
8	Vibration/	26747
9	vibrat*.mp.	93579
10	8 or 9	93579
11	7 and 10	463

PubMed:

Search	Actions	Details	Query	Results	Time
#8	•••	⌄	Search: **(periodont*) AND (high frequency vibration)** "periodont*"[All Fields] AND ("high"[All Fields] AND ("epidemiology"[MeSH Subheading] OR "epidemiology"[All Fields] OR "frequency"[All Fields] OR "epidemiology"[MeSH Terms] OR "frequence"[All Fields] OR "frequences"[All Fields] OR "frequencies"[All Fields]) AND ("vibrate"[All Fields] OR "vibrated"[All Fields] OR "vibrates"[All Fields] OR "vibrating"[All Fields] OR "vibration"[MeSH Terms] OR "vibration"[All Fields] OR "vibrations"[All Fields] OR "vibrational"[All Fields] OR "vibrator"[All Fields] OR "vibrators"[All Fields])) **Translations** **frequency:** "epidemiology"[Subheading] OR "epidemiology"[All Fields] OR "frequency"[All Fields] OR "epidemiology"[MeSH Terms] OR "frequence"[All Fields] OR "frequences"[All Fields] OR "frequencies"[All Fields] **vibration:** "vibrate"[All Fields] OR "vibrated"[All Fields] OR "vibrates"[All Fields] OR "vibrating"[All Fields] OR "vibration"[MeSH Terms] OR "vibration"[All Fields] OR "vibrations"[All Fields] OR "vibrational"[All Fields] OR "vibrator"[All Fields] OR "vibrators"[All Fields]	28	01:03:49

#7	•••	⌄	Search: **(periodontal lig*) AND (vibrat*)** ("periodontal"[All Fields] OR "periodontally"[All Fields] OR "periodontically"[All Fields] OR "periodontics"[MeSH Terms] OR "periodontics"[All Fields] OR "periodontic"[All Fields] OR "periodontitis"[MeSH Terms] OR "periodontitis"[All Fields] OR "periodontitides"[All Fields]) AND "lig"[All Fields] AND "vibrat*"[All Fields] **Translations** **periodontal:** "periodontal"[All Fields] OR "periodontally"[All Fields] OR "periodontically"[All Fields] OR "periodontics"[MeSH Terms] OR "periodontics"[All Fields] OR "periodontic"[All Fields] OR "periodontitis"[MeSH Terms] OR "periodontitis"[All Fields] OR "periodontitides"[All Fields]	0	01:02:23
#6	•••	⌄	Search: **(periodontal lig*) AND (vibrat*) - Schema: all** "periodontal"[All Fields] AND "lig"[All Fields] AND "vibrat*"[All Fields]	0	01:02:23
#5	•••	⌄	Search: **(periodont*) AND (vibration)** "periodont*"[All Fields] AND ("vibrate"[All Fields] OR "vibrated"[All Fields] OR "vibrates"[All Fields] OR "vibrating"[All Fields] OR "vibration"[MeSH Terms] OR "vibration"[All Fields] OR "vibrations"[All Fields] OR "vibrational"[All Fields] OR "vibrator"[All Fields] OR "vibrators"[All Fields]) **Translations** **vibration:** "vibrate"[All Fields] OR "vibrated"[All Fields] OR "vibrates"[All Fields] OR "vibrating"[All Fields] OR "vibration"[MeSH Terms] OR "vibration"[All Fields] OR "vibrations"[All Fields] OR "vibrational"[All Fields] OR "vibrator"[All Fields] OR "vibrators"[All Fields]	292	01:01:22
#4	•••	⌄	Search: **(periodont) AND (vibration)** "periodont"[All Fields] AND ("vibrate"[All Fields] OR "vibrated"[All Fields] OR "vibrates"[All Fields] OR "vibrating"[All Fields] OR "vibration"[MeSH Terms] OR "vibration"[All Fields] OR "vibrations"[All Fields] OR "vibrational"[All Fields] OR "vibrator"[All Fields] OR "vibrators"[All Fields]) **Translations** **vibration:** "vibrate"[All Fields] OR "vibrated"[All Fields] OR "vibrates"[All Fields] OR "vibrating"[All Fields] OR "vibration"[MeSH Terms] OR "vibration"[All Fields] OR "vibrations"[All Fields] OR "vibrational"[All Fields] OR "vibrator"[All Fields] OR "vibrators"[All Fields]	0	01:01:08
#3	•••	⌄	Search: **(periodont) AND (vibration) - Schema: all** "periodont"[All Fields] AND "vibration"[All Fields]	0	01:01:08

#2 ••• ⌄ Search: **(periodontology) AND (high frequency vibration)** 12 01:00:42

("periodontics"[MeSH Terms] OR "periodontics"[All Fields] OR "periodontology"[All Fields]) AND ("high"[All Fields] AND ("epidemiology"[MeSH Subheading] OR "epidemiology"[All Fields] OR "frequency"[All Fields] OR "epidemiology"[MeSH Terms] OR "frequence"[All Fields] OR "frequences"[All Fields] OR "frequencies"[All Fields]) AND ("vibrate"[All Fields] OR "vibrated"[All Fields] OR "vibrates"[All Fields] OR "vibrating"[All Fields] OR "vibration"[MeSH Terms] OR "vibration"[All Fields] OR "vibrations"[All Fields] OR "vibrational"[All Fields] OR "vibrator"[All Fields] OR "vibrators"[All Fields]))

Translations

periodontology: "periodontics"[MeSH Terms] OR "periodontics"[All Fields] OR "periodontology"[All Fields]
frequency: "epidemiology"[Subheading] OR "epidemiology"[All Fields] OR "frequency"[All Fields] OR "epidemiology"[MeSH Terms] OR "frequence"[All Fields] OR "frequences"[All Fields] OR "frequencies"[All Fields]
vibration: "vibrate"[All Fields] OR "vibrated"[All Fields] OR "vibrates"[All Fields] OR "vibrating"[All Fields] OR "vibration"[MeSH Terms] OR "vibration"[All Fields] OR "vibrations"[All Fields] OR "vibrational"[All Fields] OR "vibrator"[All Fields] OR "vibrators"[All Fields]

#1 ••• ⌄ Search: **(periodontics) AND (high-frequency vibration)** 11 00:59:24

("periodontal"[All Fields] OR "periodontally"[All Fields] OR "periodontically"[All Fields] OR "periodontics"[MeSH Terms] OR "periodontics"[All Fields] OR "periodontic"[All Fields] OR "periodontitis"[MeSH Terms] OR "periodontitis"[All Fields] OR "periodontitides"[All Fields]) AND ("high-frequency"[All Fields] AND ("vibrate"[All Fields] OR "vibrated"[All Fields] OR "vibrates"[All Fields] OR "vibrating"[All Fields] OR "vibration"[MeSH Terms] OR "vibration"[All Fields] OR "vibrations"[All Fields] OR "vibrational"[All Fields] OR "vibrator"[All Fields] OR "vibrators"[All Fields]))

Translations

periodontics: "periodontal"[All Fields] OR "periodontally"[All Fields] OR "periodontically"[All Fields] OR "periodontics"[MeSH Terms] OR "periodontics"[All Fields] OR "periodontic"[All Fields] OR "periodontitis"[MeSH Terms] OR "periodontitis"[All Fields] OR "periodontitides"[All Fields]
vibration: "vibrate"[All Fields] OR "vibrated"[All Fields] OR "vibrates"[All Fields] OR "vibrating"[All Fields] OR "vibration"[MeSH Terms] OR "vibration"[All Fields] OR "vibrations"[All Fields] OR "vibrational"[All Fields] OR "vibrator"[All Fields] OR "vibrators"[All Fields]

SCOPUS:

289 document results

(TITLE-ABS-KEY (periodont*) AND TITLE-ABS-KEY (vibrat*))

22 document results

(TITLE-ABS-KEY (periodont*) AND TITLE-ABS-KEY (high-frequency AND vibration))

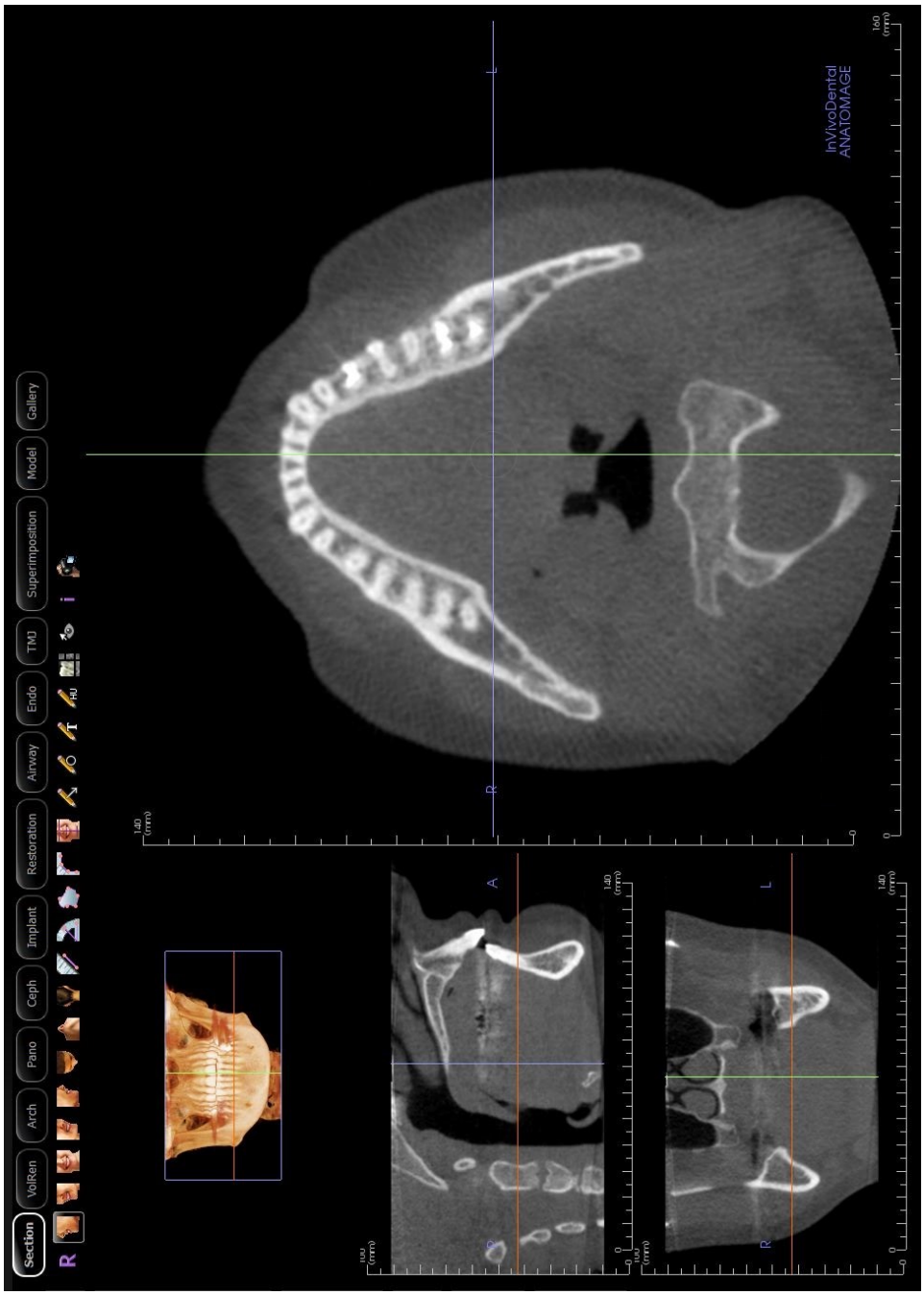
244 document results

(TITLE-ABS-KEY (periodontal) AND TITLE-ABS-KEY (vibrat*))

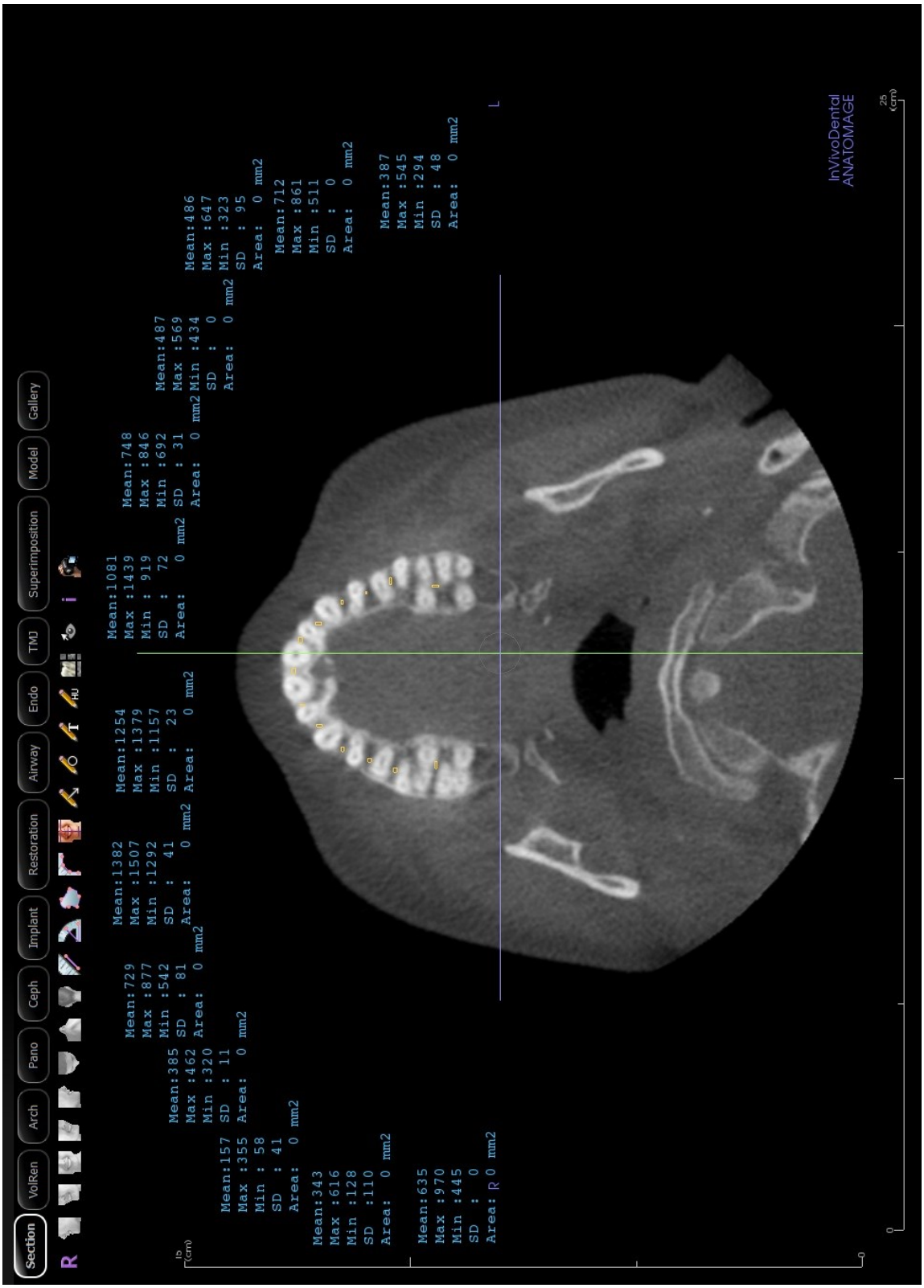
Appendix C

Estimation of Bone Mineral Density (Hounsfield Units):

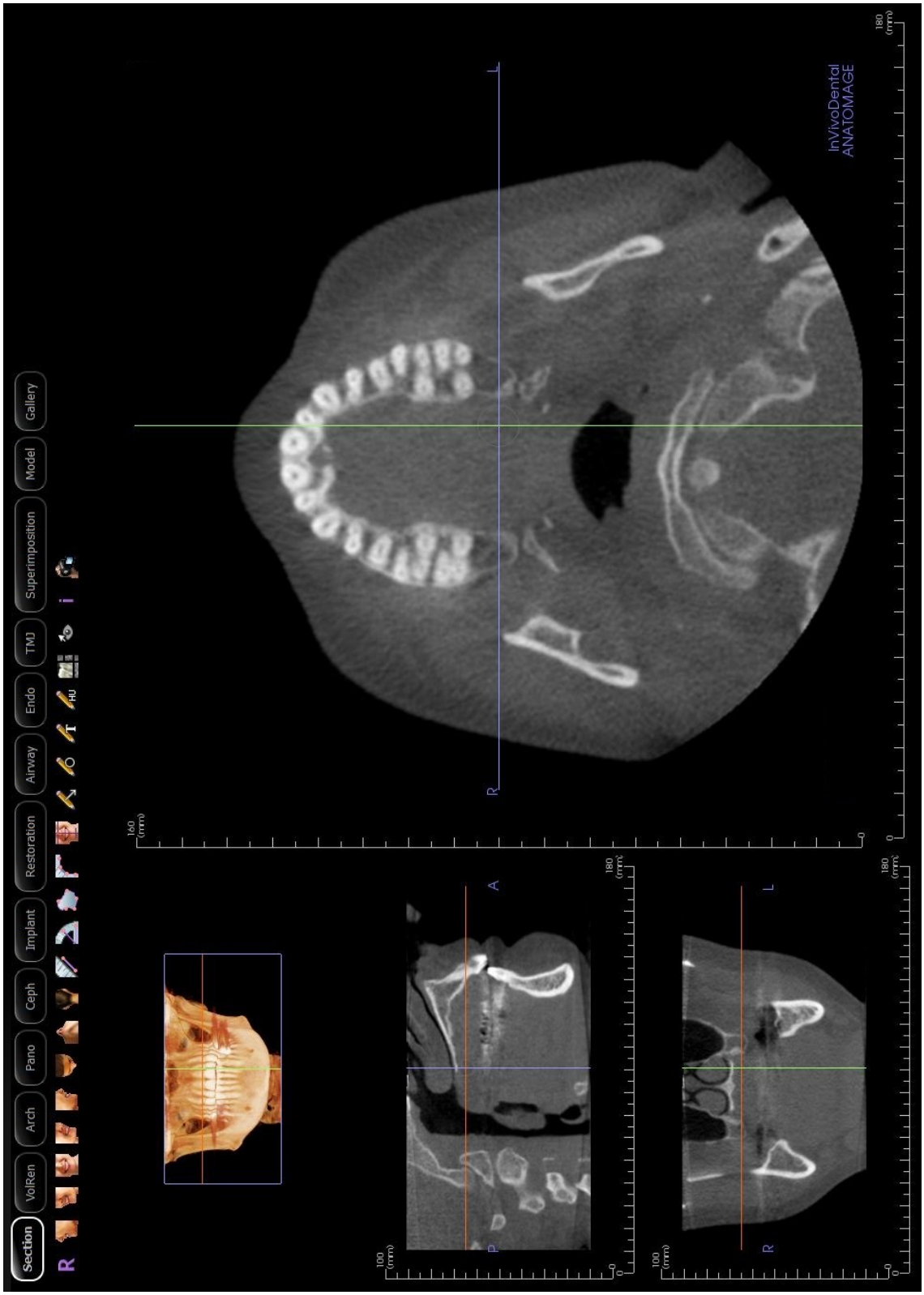
- **Baseline CBCT maxillary axial plane**



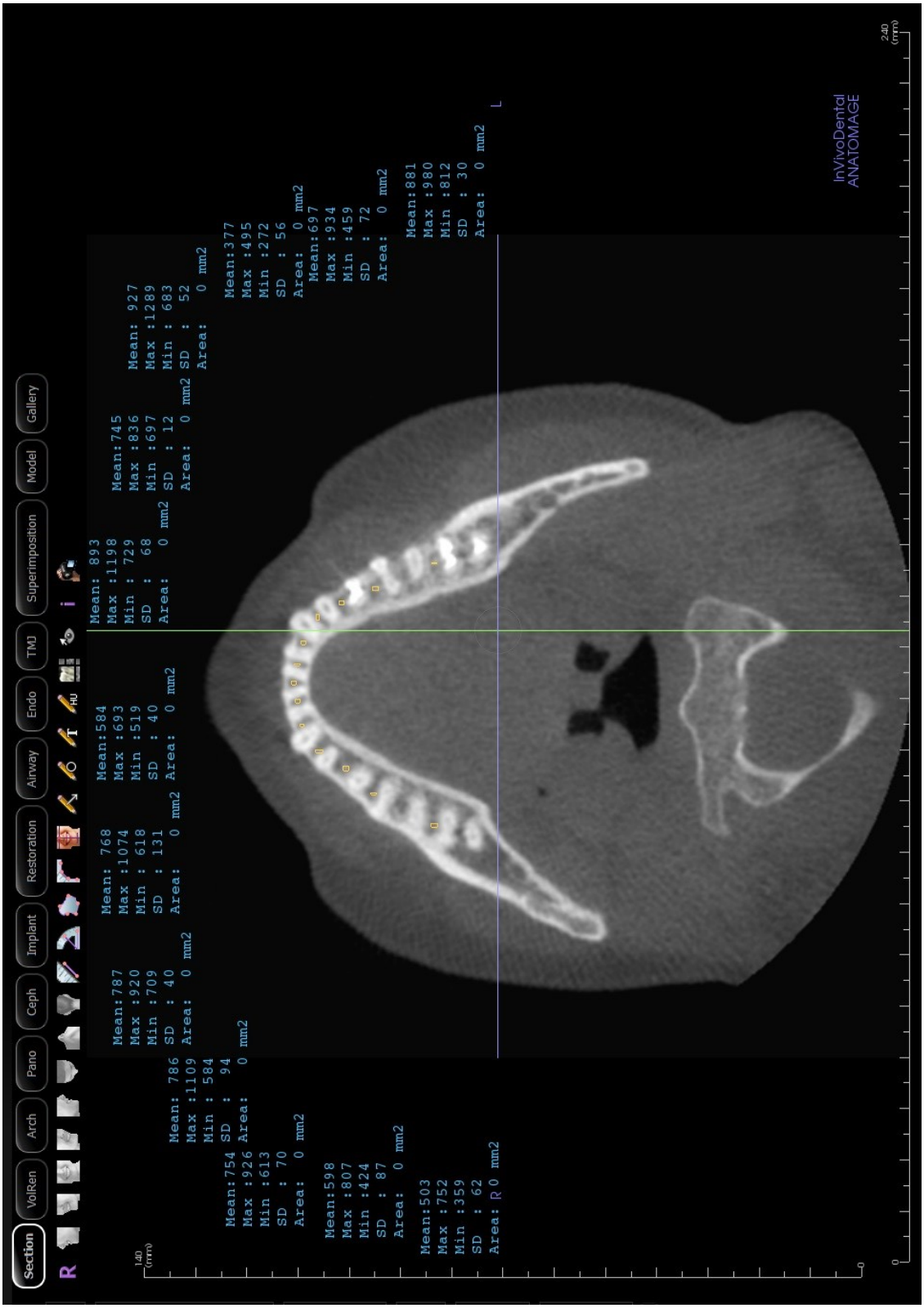
- **Baseline maxillary BMD measurements in Hounsfield unit**



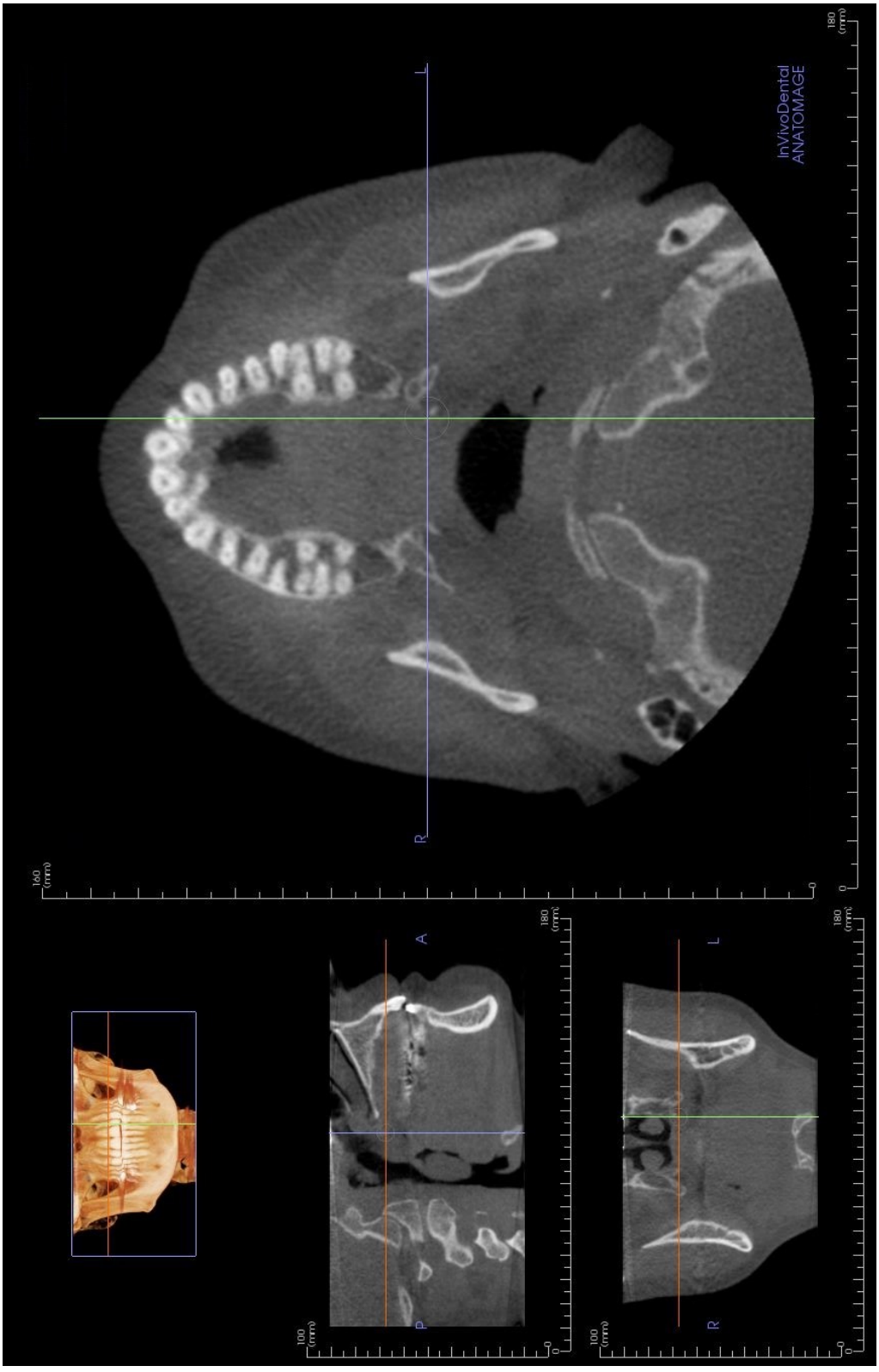
- **Baseline CBCT mandibular axial plane**



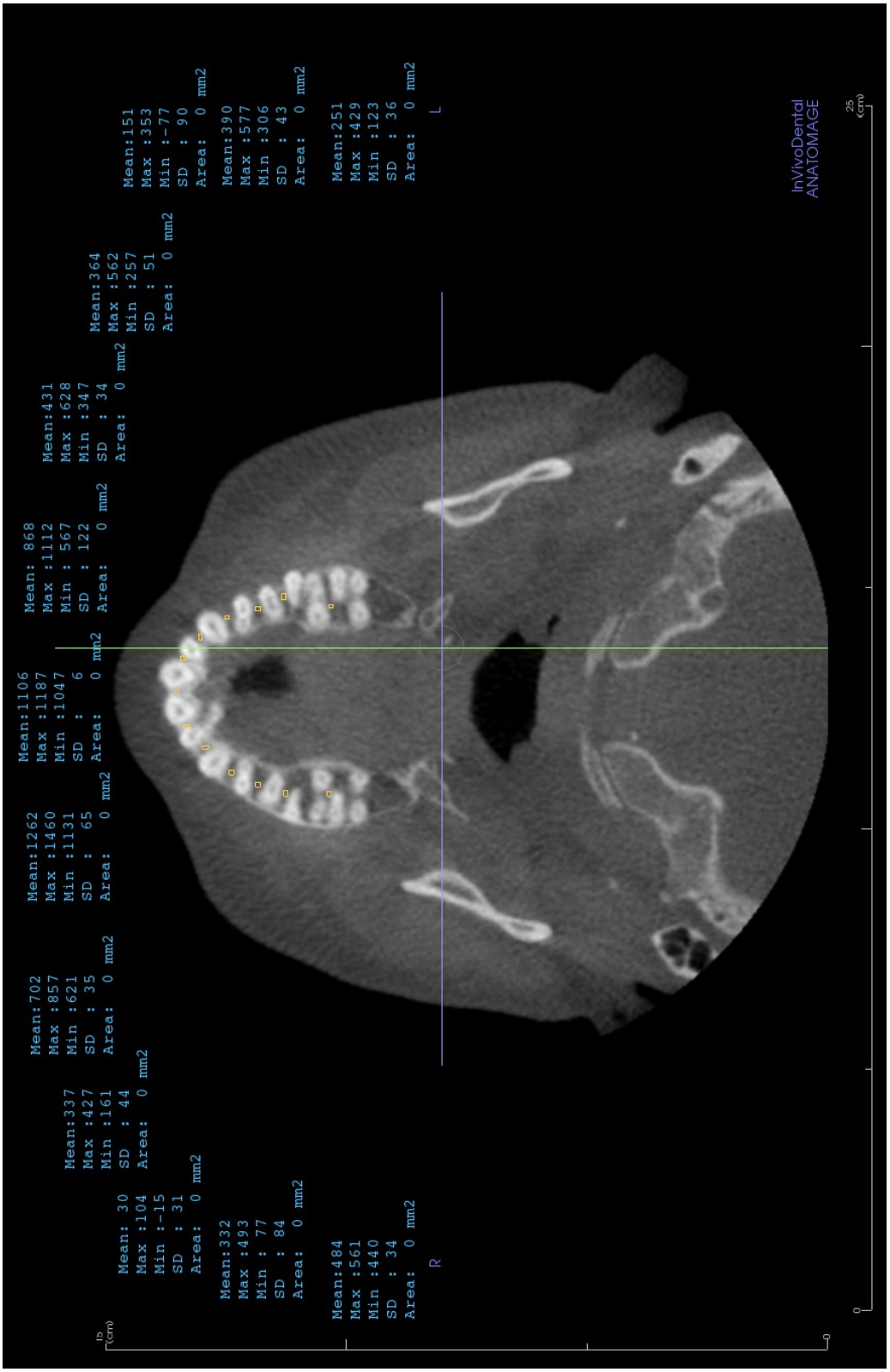
- **Baseline mandibular BMD measurements in Hounsfield unit**



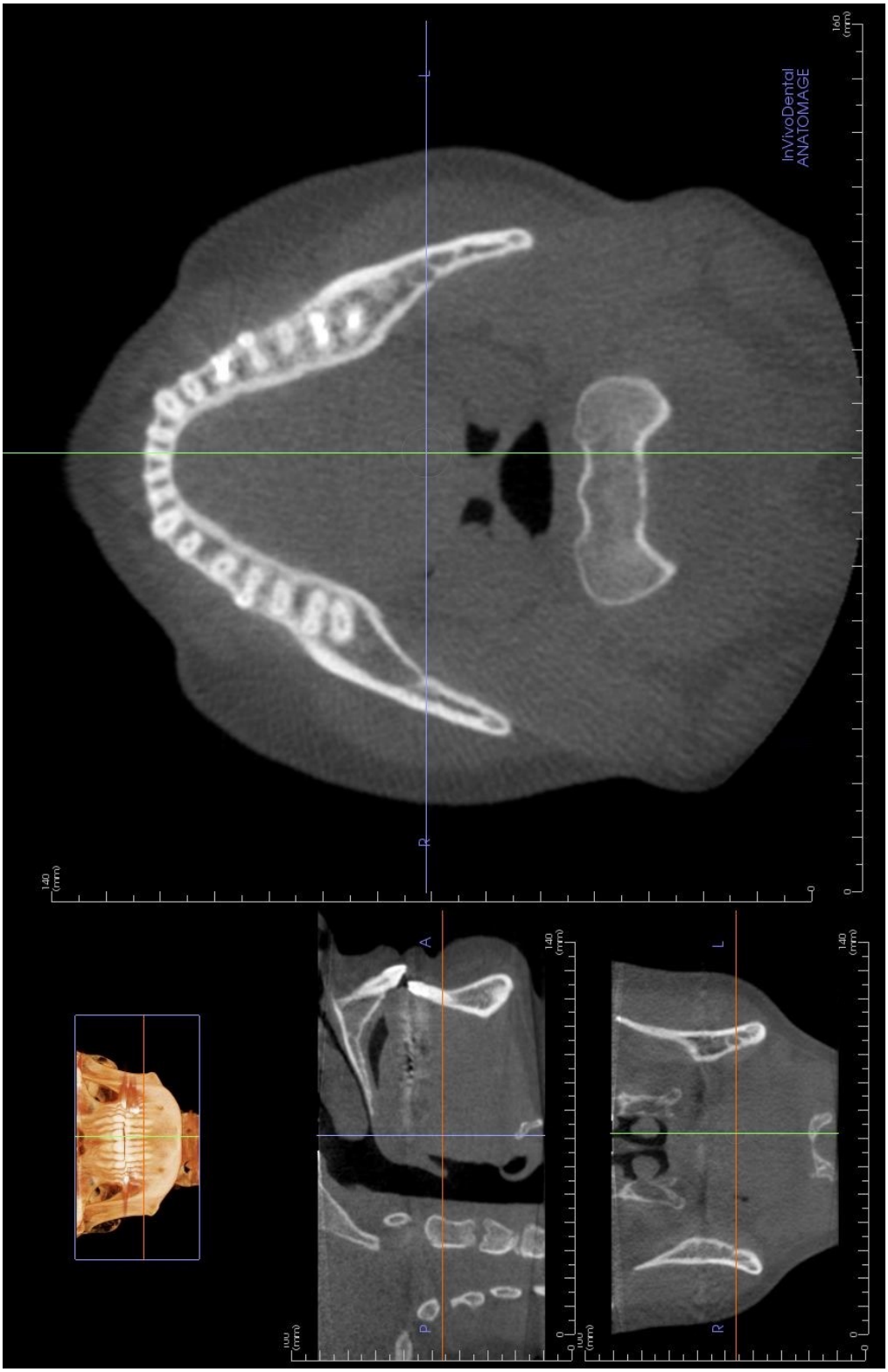
- **3-month CBCT maxillary axial plane**



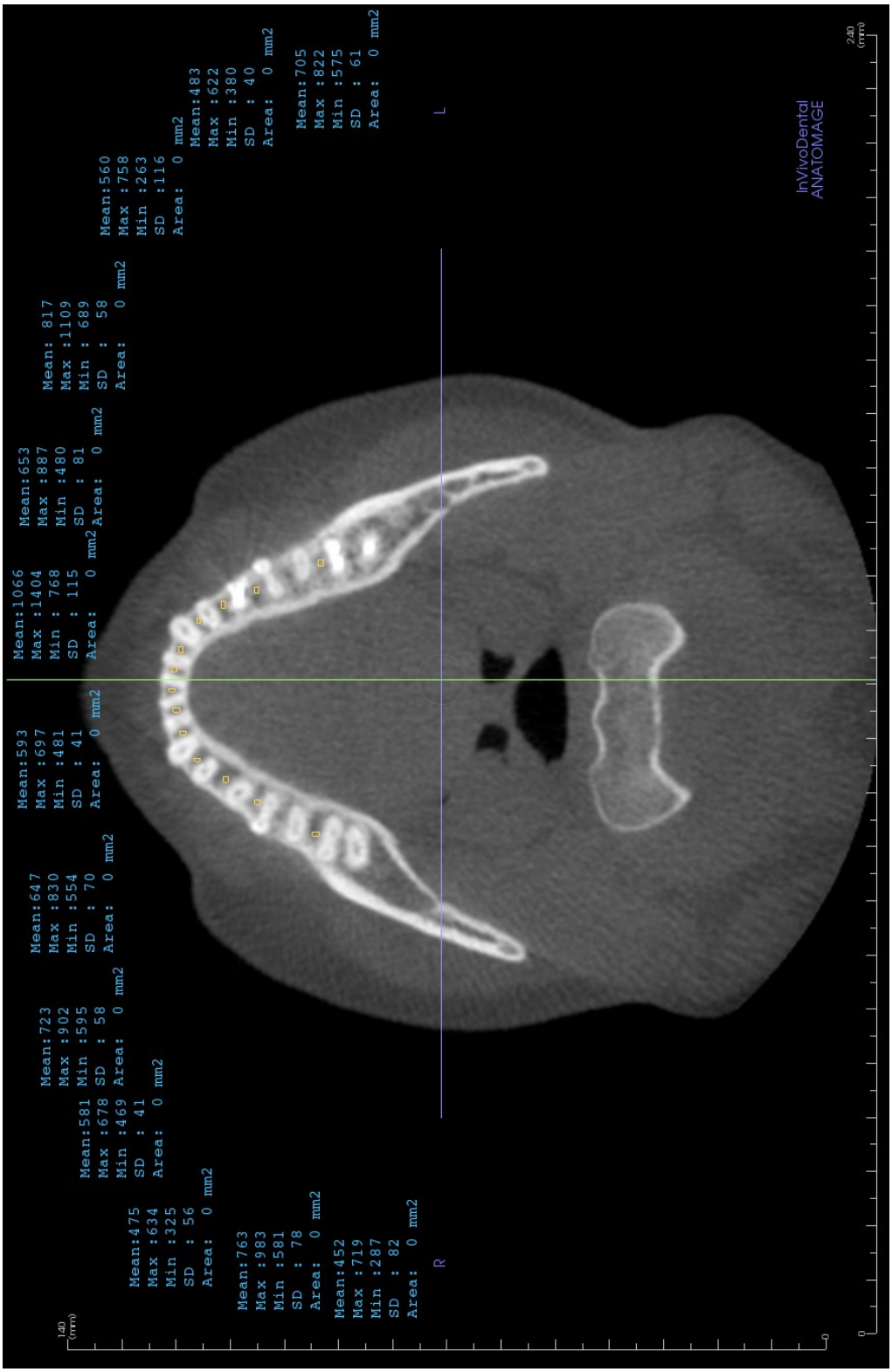
- **3-month maxillary BMD measurements in Hounsfield unit**



- **3-month CBCT mandibular axial plane**

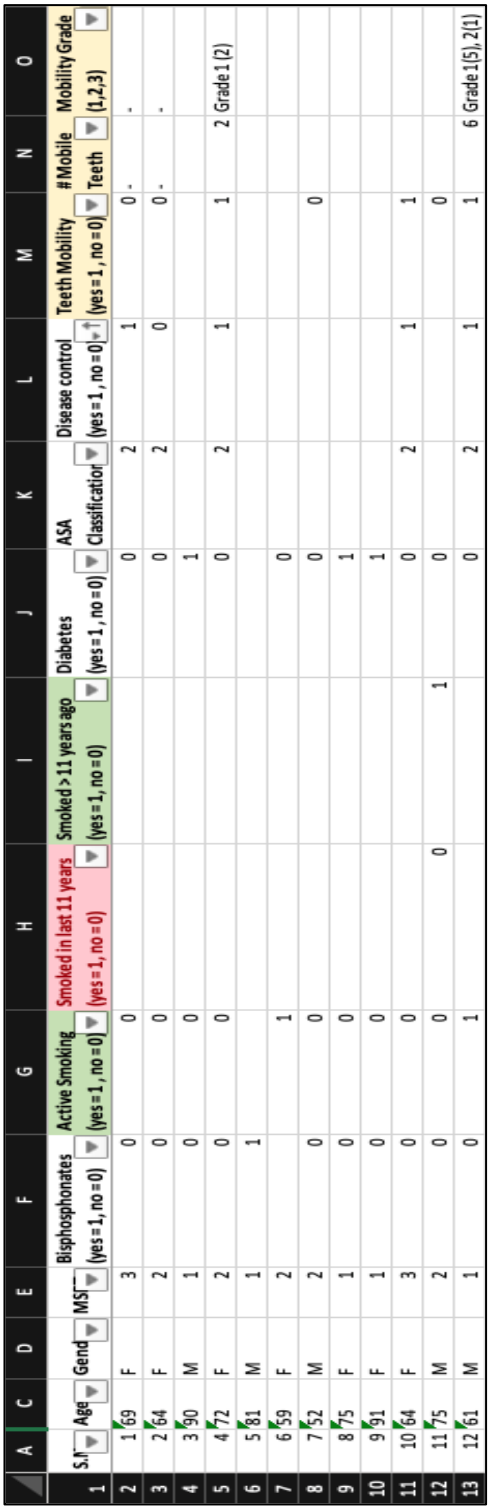


- **3-month mandibular BMD measurements in Hounsfield unit**



Appendix D

Ms. Excel sheet imported 243 charts and extracted data by reading each chart



S.No	Age	Gender	MSE	Bisphosphonates (yes=1, no=0)	Active Smoking (yes=1, no=0)	Smoked in last 11 years (yes=1, no=0)	Smoked >11 years ago (yes=1, no=0)	Diabetes (yes=1, no=0)	ASA Classification	Disease control (yes=1, no=0)	Teeth Mobility (yes=1, no=0)	#Mobile Teeth	Mobility Grade (1,2,3)
1	69	F	3	0	0			0	2	1	0	-	-
2	64	F	2	0	0				2	0	0	-	-
3	90	M	1	0	0			1					
4	72	F	2	0	0			0	2	1	1	2	Grade 1 (2)
5	81	M	1	1									
6	59	F	2		1			0					
7	52	M	2	0	0			0			0		
8	75	F	1	0	0			1					
9	91	F	1	0	0			1					
10	64	F	3	0	0			0	2	1	1		
11	75	M	2	0	0	0	1	0			0		
12	61	M	1	0	1			0	2	1	1	6	Grade 1(5), 2(1)

Appendix E

Script used to contact patients:

Script for calling potential HFV research patients:

Good-morning/Good-afternoon Mr. Smith/Ms. Brown,

How are you doing today. My name is Dr. Sameer Bajaj and I am calling you from Graduate Periodontics Department at University of Alberta. Is this a good time to speak to you for 5 minutes. If the patient says yes, then continue.

The reason for my call today is to discuss a research opportunity with you. In our regular chart audits, your chart was selected based on a very specific and strict inclusion criterion (if they ask, talk about non-smoker, non-diabetic, no bisphosphonate use and relatively stable periodontal disease).

Some initial studies have shown that the use of vibration devices may strengthen the bone around loose teeth in absence of any clinical signs of inflammation. To date, no definitive research results have told us whether the use of vibration can help make loose teeth become tight by growing bone around the teeth.

If you agree to participate in this study, you will be randomly assigned to one of two groups (like rolling a dice). One group will be asked to bite on an active, vibrating device for 5 minutes per day for 3 months. The second group will be asked to do the same but using instead a device that does not vibrate. You will not have a choice as to what group that you get assigned to. The vibration device is called PTech vibratory device, produced by Periotech Company, California, USA. This device is approved both by FDA (Food and Drug Administration of the United States) and Health Canada.

We will be doing a full set of x-rays including a three-dimensional x-ray and an exam. These X-rays will also help in terms of seeing if you need future treatment or not and tell us how healthy your mouth is. We will be doing both, the exams, and the X-rays at baseline and at 3 months. As a patient, if you choose to participate in the research project, you will not be charged for the exams and the X-rays.

If you are interested, Amy our treatment coordinator will make appointment for you accordingly.

Thank you.

Appendix F

Consent Form:

Effect of High Frequency Vibration on Periodontal Tooth Mobility

Principal Investigator:
Dr. Douglas Dederich | Phone Number: +1(780) 492-6256

Co-Investigator:
Dr. Sameer Bajaj | Phone Number: +1(780) 407-5528

Background: You are being asked to be in a research study because you are undergoing a periodontal maintenance therapy every three – four months. Periodontal disease if uncontrolled can cause problems like loose mobile teeth and bone loss around teeth. In severe cases this can lead to tooth loss. Some initial studies have shown that the use of vibration devices may strengthen the bone around loose teeth in absence of any clinical signs of inflammation. To date, no definitive research results have told us whether the use of vibration can help lower the mobility of teeth. This is why we are doing this study.

Before you make a decision one of the researchers will go over this form with you. You are encouraged to ask questions if you feel anything needs to be made clearer. You will be given a copy of this form for your records.

Purpose: You are being asked to participate in a research study which will evaluate whether vibration of the teeth can strengthen the bone around the roots of the teeth and decrease the mobility of the teeth. If you agree to be in this study you will be randomly assigned to one of two groups (like rolling a dice). One group with be asked to bite on an active, vibrating device for 5 minutes per night for 3 months. The second group will be asked to do the same, but using instead a "sham" device that does not vibrate. You will not have a choice of what group that you get assigned to. The vibration device is called Vpro5, produced by Propel Company, California, USA. These devices are approved by FDA (Food and Drug Administration of the United States) and Health Canada.

Procedures: If you agree to be in this study, you will first sign this consent document. Your standard periodontal maintenance therapy routine will not change as a result of your being in this study, except for being assigned to one of the two groups as described above. A CBCT scan (3D Scan) will be taken both at the beginning (baseline) and at the end of the study. The expected duration of the research is three months.

However you will continue your periodontal maintenance therapy on regular basis after the research is completed. **Any treatment done in the Graduate Periodontology Clinic for the purposes of this study will be done at no charge to you.** Once the study is done, you will be charged as usual for any treatment provided.

COVID-19 Precautions: Since the appointments for your periodontal maintenance therapy happen in the Oral Health Clinic, Graduate Periodontology program located on the 8th floor of Kaye Edmonton Clinic, we are obliged to inform you, as part of your consent to participate, of potential additional risks due to COVID-19. Risks associated with this include increased exposure to other people since there is an increased time in travel and increase time in the health care facility. Measures undertaken to reduce this risk include screenings of people entering the Kaye Edmonton Health Clinic, usage and provision of PPE (masks and gloves), use and provision of hand sanitizers and applying of physical distancing measures where possible inside the clinic.

Your voluntary participation in this study will involve:

a. The Graduate Periodontology program will provide you with some forms to report on any pain/discomfort that you may encounter while wearing the vibration device. Your visit to the clinic will be as regular periodontal maintenance therapy appointment (every 3-4 months). These forms will not be part of your dental records, they are only for research.
b. A review of your dental records for information about the nature of your periodontal issue, mobility and possible pain if any.
c. During your first study visit, a complete periodontal examination will be taken, a (cone-beam Computed Tomographic x-ray) [CBCT] scan which is a small field of x-ray to show us the teeth from different aspects with very low amount of radiation. Your regular maintenance (deep cleaning/scaling/root planning will be done by a graduate periodontology resident)
d. Subsequent visit (3 months later) will involve complete periodontal measurements and a (cone-beam computed tomographic x-ray) [CBCT] scan.
e. After 3 months, the research part will be finished and your regular treatment will continue. (See Table below showing schedule of appointments).
f. **Any treatment done in the Graduate Periodontology Clinic for the purposes of this study will be done at no charge to you.**

Possible Benefits: Because we do not know if using these vibration devices will offer any benefits, any direct personal health benefits cannot be guaranteed. We hope that information obtained from this study could help improve the periodontal health of recall patients in the future. Other than having the opportunity to get free periodontal care for a short period of time, there may be no health benefit to you for participating in the study.

Possible Risks: We anticipate the risk associated with the use of the vibration device in this study is similar to the risk associated with the use of an electric toothbrush. You will also be exposed to a small amount of radiation from the full mouth series of X-rays and the CBCT imaging required at the beginning and end of the study. The risk from this amount of radiation has been categorized by the AHS Regional Radiation Safety Committee as "*very low*". The use of a CBCT is a norm when planning for dental implants and other dental surgeries.

Confidentiality: Personal records relating to this study will be kept confidential. Any research data collected about you during this study will not identify you by name, only a unique number. Your name will not be disclosed outside the research clinic. Any report published as a result of this study will not identify you by name.

The study doctor may need to look at your personal dental health records held at the Graduate Periodontology program, School of Dentistry, University of Alberta. Any personal information we get from these records will be only what is needed for the study and will not be included in the study data record.

During research studies, it is important that the data we get is accurate. For this reason, your health data, including your name, may be looked at by people from the University of Alberta auditors, members of the Health Research Ethics Board, and/or Health Canada. By signing this consent form you are giving permission to the study doctor to collect, use and disclose information about you from your personal health records, as described above. Data will be provided to the sponsor or third party without any name or identifiers of you.

After the study is done, we will still need to securely store your health data that was collected as part of the study. The data will be stored for 5 years.

Voluntary Participation: You do not have to be in this study to receive your periodontal maintenance therapy at Graduate Periodontology program, School of Dentistry, University of Alberta. Further, even if you agree to be in the study, you are free to withdraw at any time, and your periodontal care will not be affected in any way. If you withdraw from the study, no further testing

with your gum tissue or teeth will be done. We will keep the data that we collected before you withdrew but will not collect any more data. The treatment you receive as a part of the study will be at no charge to you. Once the study is done or you have withdrawn from the study, any treatment you receive in the Graduate Periodontology Clinic will be charged to you as usual.

Study Visits will be as follows:
Visit 1: ***Case Work-Up* and *1st Recall Cleaning Visit (Time=0)***

Obtain informed consent (to be done on email if possible)	5 min
Complete Patient Health History Form (to be done over the phone)	10 min
Complete Periodontal Examination	30 min
Randomize and assign into control/experimental groups	5 min
Periodontal Recall Cleaning and device is given to them.	40 min
Total appointment time (in chair)	**90 min**

Visit 2: ***2nd 3-month Recall Cleaning Visit (Time=3 months)***

Complete Periodontal Examination by PI	30 min
Periodontal Recall Cleaning and device is collected back from them.	60 Min
Total appointment time (in chair)	**90 min**

Alternatives: You do not have to join this study to receive treatment. If you choose not to participate, you will have the option to continue your regular periodontal treatment as usual.

Cost/Compensation: There will be **NO cost** to you for participating in this study. You will not receive any payment for being in this study. The treatment you receive as part of this study will be at no cost to you. Once the study is done or if you choose to withdraw from the study, your periodontal maintenance therapy with the hygienist will be charged as per the rates set out by the Graduate Periodontology program, School of Dentistry, University of Alberta.

Compensation for Injury: There are no provisions for additional medical or dental treatment that may be required as a result of being in this study. By signing this consent form you are not releasing the investigator(s), institution(s) and/or sponsor(s) from their legal and professional responsibilities.

Contact Names and Telephone Numbers: If you have any concerns regarding your rights as a study participant, you may contact the University of Alberta Research Ethics Office at 780-492-2615. This office is independent of the study doctor.

Please contact Dr. Douglas N. Dederich if you have any questions about the study or if you feel like you may have suffered a research related injury:

Dr. Douglas N. Dederich, BSEE, DDS, MSc, PhD, Cert. Perio.
Professor and Co-Director of Graduate Periodontics
5-467 Edmonton Clinic Health Academy
School of Dentistry, Faculty of Medicine and Dentistry
University of Alberta, Edmonton AB T6G 1C9
Email: dederich@ualberta.ca

Phone: +1 (780) 492-6256

CONSENT FORM

Effect of High Frequency Vibration on Periodontal Tooth Mobility

Principal Investigator: Dr. Douglas N. Dederich | +1 (780) 492-6256

	Yes	No
Do you understand that you have been asked to be in a study?	☐	☐
Have you read and received a copy of the attached Information Sheet?	☐	☐
Do you understand the benefits and risks involved in taking part in this research study?	☐	☐
Have you had an opportunity to ask questions and discuss this study?	☐	☐
Do you understand that you are free to refuse to participate or withdraw from the research study at any time? This will not affect your treatment in the graduate periodontology program.	☐	☐
Do you understand who will have access to your records, including personally identifiable health information?	☐	☐

Who explained this study to you? _____

I agree to take part in this study: YES ☐ NO ☐

Participant's Signature _____

Printed Name _____ Date _____

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.

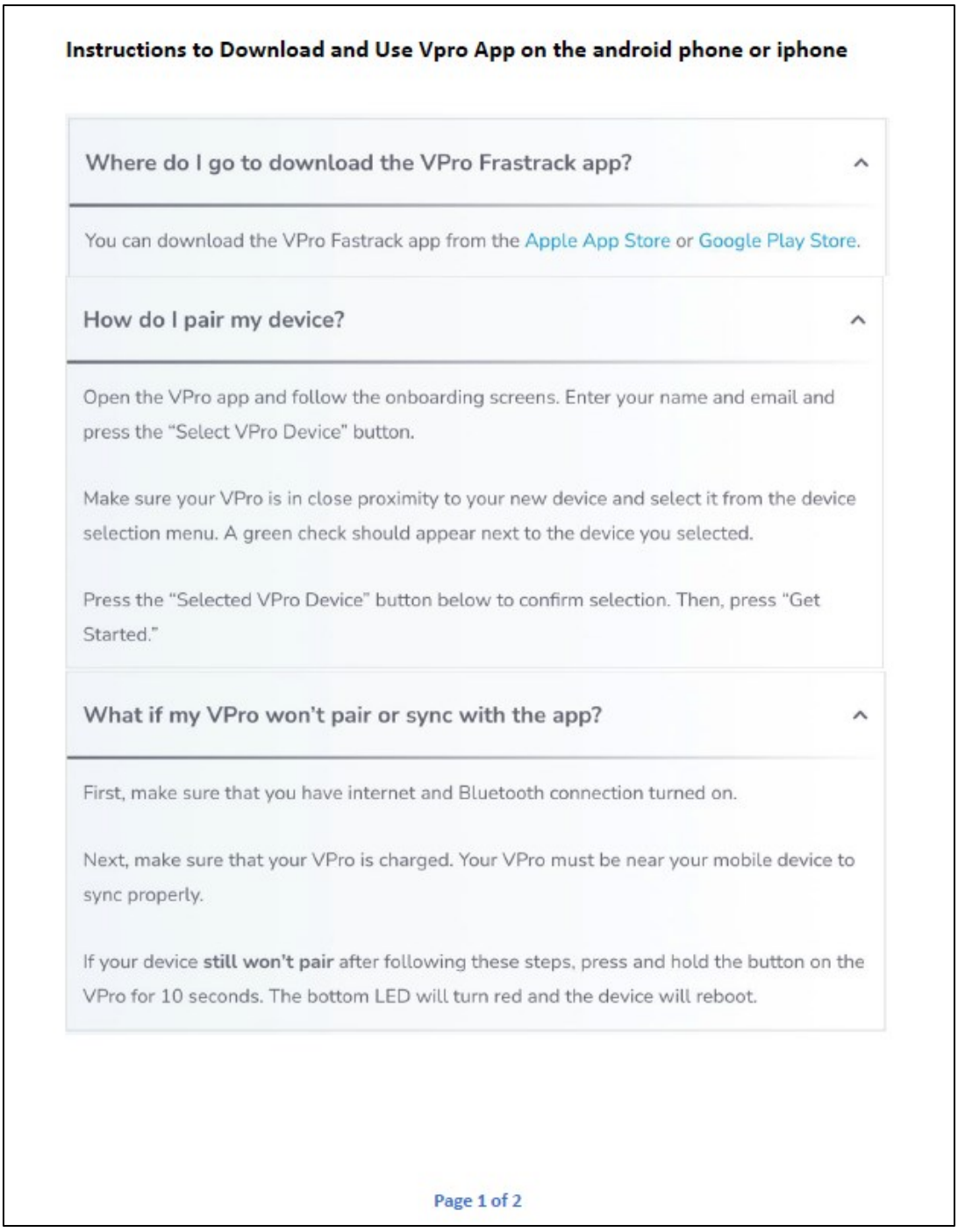
Signature of Investigator or Designee _____

Date _____

THE INFORMATION SHEET MUST BE ATTACHED TO THIS CONSENT FORM AND A COPY GIVEN TO THE RESEARCH PARTICIPANT

Appendix G

Instructions to Download and Use Vpro+ app:



Instructions to Download and Use Vpro App on the android phone or iphone

Where do I go to download the VPro Frastrack app?

You can download the VPro Fastrack app from the Apple App Store or Google Play Store.

How do I pair my device?

Open the VPro app and follow the onboarding screens. Enter your name and email and press the "Select VPro Device" button.

Make sure your VPro is in close proximity to your new device and select it from the device selection menu. A green check should appear next to the device you selected.

Press the "Selected VPro Device" button below to confirm selection. Then, press "Get Started."

What if my VPro won't pair or sync with the app?

First, make sure that you have internet and Bluetooth connection turned on.

Next, make sure that your VPro is charged. Your VPro must be near your mobile device to sync properly.

If your device **still won't pair** after following these steps, press and hold the button on the VPro for 10 seconds. The bottom LED will turn red and the device will reboot.

Page 1 of 2

How do I identify which device to pair to if multiple devices are available?

Attempt to limit the number of other VPro devices displayed on your pairing screen by taking your mobile device and VPro to a space separate from other VPro devices.

Additionally, ensure that your VPro and your mobile device are in close proximity to each other.

The VPro displayed at the top of your app is the device with the strongest signal, meaning it is the device closest to your phone. Pair to this device.

To ensure you have successfully paired to your device, use the "Locate Device" feature present in the Settings section of the app to vibrate your device.

I typically have Bluetooth turned off. Can I still use this app?

Bluetooth does need to be enabled on your device in order for your VPro to sync to the app.

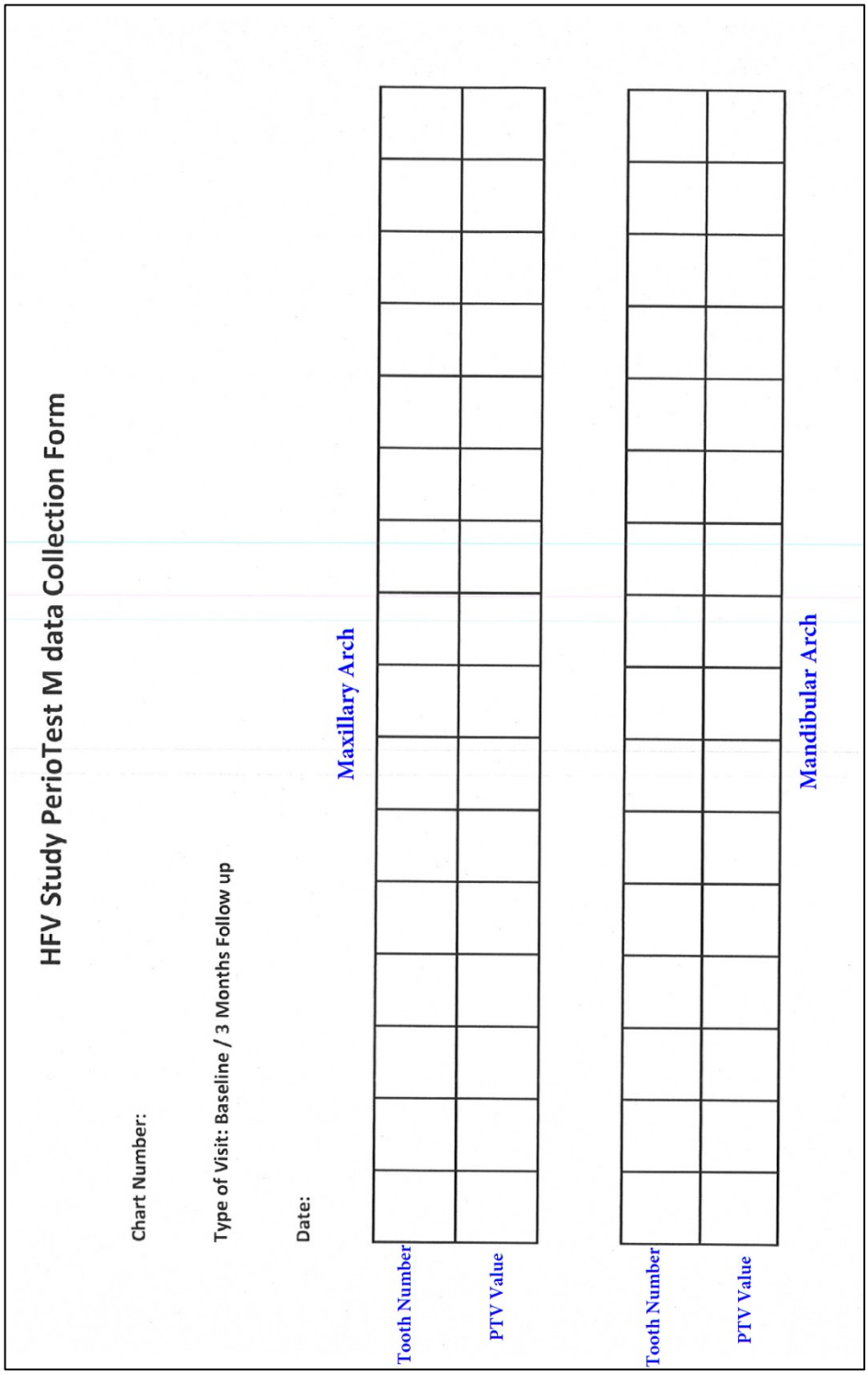
If you **do not** have Bluetooth enabled, VPro will store your data until it can sync with your device again.

As long as you enable Bluetooth on your device with your VPro nearby, you can successfully sync your data when you want.

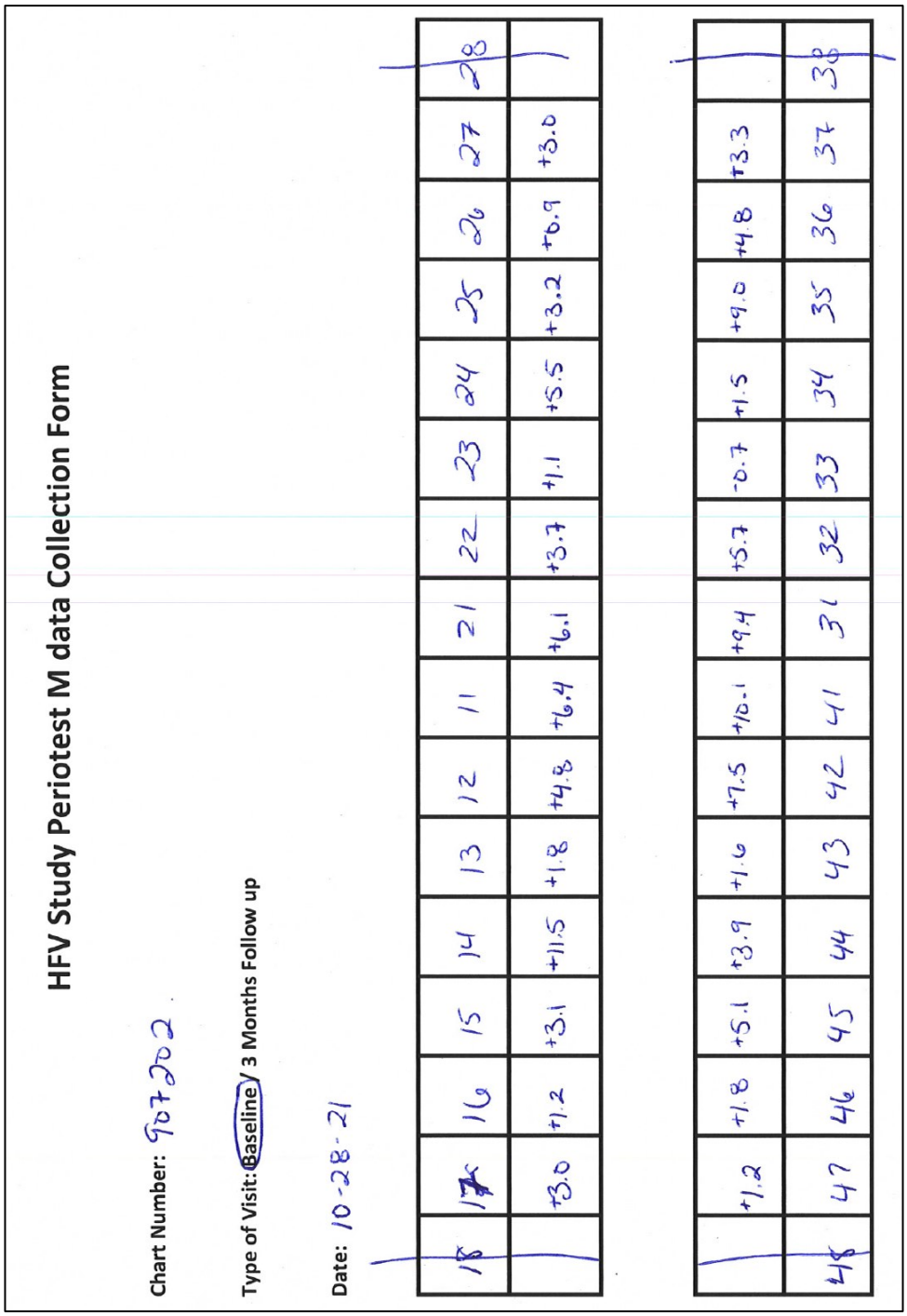
Link for more FAQ's: https://propelorthodontics.com/frequently-asked-questions/

Appendix H

Chairside Periotest Data Collection Template:



Example of Periotest Data Entry (Baseline Visit):



HFV Study Periotest M data Collection Form

Chart Number: 907202

Type of Visit: Baseline / 3 Months Follow up

Date: 10-28-21

18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
	+3.0	+1.2	+3.1	+11.5	+1.8	+4.8	+6.4	+6.1	+3.7	+1.1	+5.5	+3.2	+0.9	+3.0	

	+1.2	+1.8	+5.1	+3.9	+1.6	+7.5	+10.1	+9.4	+5.7	-0.7	+1.5	+9.0	+4.8	+3.3	
48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Appendix I

Data transformation for the Periotest value:

	A	B	C	D
1	Teeth	Baseline PTV	Follow Up PTV	Group
2	1	5.2	4.9	Control
3	2	19.5	20.8	Control
4	3	3.9	3.5	Control
5	4	5.1	4.2	Control
6	5	4	4.6	Control
7	7	4.2	3.6	Control
8	8	5.4	4.1	Control
9	9	35.3	33.4	Control
10	10	-1.1	-2.2	Control

Data transformation for the Hounsfield Unit value:

	A	B	C	D
1	Teeth	Baseline HU	Follow Up HU	Group
2	1	1021	1119	Control
3	2	1074	996	Control
4	3	1149	1235	Control
5	4	914	783	Control
6	5	534	431	Control
7	6	373	333	Control
8	7	85	114	Control
9	8	1021	1119	Control
10	9	989	996	Control
11	10	554	633	Control

Appendix J

Statistical Analysis for the Periotest value for entire data set:

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Baseline PTV	Control	4.864	5.1222	220
	Test	6.962	6.6029	196
	Total	5.852	5.9523	416
Follow Up PTV	Control	5.265	5.6840	220
	Test	7.126	6.7900	196
	Total	6.142	6.2910	416

Tests of Within-Subjects Effects

Measure: PeriotestValue

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Time	Sphericity Assumed	16.553	1	16.553	2.689	.102	.006
	Greenhouse-Geisser	16.553	1.000	16.553	2.689	.102	.006
	Huynh-Feldt	16.553	1.000	16.553	2.689	.102	.006
	Lower-bound	16.553	1.000	16.553	2.689	.102	.006
Time * Group	Sphericity Assumed	2.926	1	2.926	.475	.491	.001
	Greenhouse-Geisser	2.926	1.000	2.926	.475	.491	.001
	Huynh-Feldt	2.926	1.000	2.926	.475	.491	.001
	Lower-bound	2.926	1.000	2.926	.475	.491	.001
Error(Time)	Sphericity Assumed	2548.701	414	6.156			
	Greenhouse-Geisser	2548.701	414.000	6.156			
	Huynh-Feldt	2548.701	414.000	6.156			
	Lower-bound	2548.701	414.000	6.156			

Tests of Between-Subjects Effects

Measure: PeriotestValue

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	30394.051	1	30394.051	453.208	.000	.523
Group	811.785	1	811.785	12.105	.001	.028
Error	27764.598	414	67.064			

Pairwise Comparisons

Measure: PTV

Time	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	Control	Test	-2.098*	.576	.000	-3.230	-.965
	Test	Control	2.098*	.576	.000	.965	3.230
2	Control	Test	-1.860*	.612	.003	-3.063	-.657
	Test	Control	1.860*	.612	.003	.657	3.063

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Pairwise Comparisons

Measure: PTV

(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	-.283	.172	.102	-.621	.056
2	1	.283	.172	.102	-.056	.621

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Pairwise Comparisons

Measure: MEASURE_1

Group	(I) time	(J) time	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
Control	1	2	-.401	.237	.091	-.866	.064
	2	1	.401	.237	.091	-.064	.866
Test	1	2	-.164	.251	.514	-.656	.329
	2	1	.164	.251	.514	-.329	.656

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Pairwise Comparisons

Measure: PTV

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
Control	Test	-1.979*	.569	.001	-3.097	-.861
Test	Control	1.979*	.569	.001	.861	3.097

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Statistical Analysis for the Hounsfield Unit (HU) value for entire data set:

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Baseline HU	Control	783.29	336.251	207
	Test	672.77	438.349	190
	Total	730.40	391.893	397
Follow Up HU	Control	731.79	332.160	207
	Test	688.78	439.515	190
	Total	711.21	387.367	397

Tests of Within-Subjects Effects

Measure: HU

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Time	Sphericity Assumed	62396.708	1	62396.708	3.965	.047
	Greenhouse-Geisser	62396.708	1.000	62396.708	3.965	.047
	Huynh-Feldt	62396.708	1.000	62396.708	3.965	.047
	Lower-bound	62396.708	1.000	62396.708	3.965	.047
Time * Group	Sphericity Assumed	225775.862	1	225775.862	14.348	.000
	Greenhouse-Geisser	225775.862	1.000	225775.862	14.348	.000
	Huynh-Feldt	225775.862	1.000	225775.862	14.348	.000
	Lower-bound	225775.862	1.000	225775.862	14.348	.000
Error(Time)	Sphericity Assumed	6215805.86	395	15736.217		
	Greenhouse-Geisser	6215805.86	395.000	15736.217		
	Huynh-Feldt	6215805.86	395.000	15736.217		
	Lower-bound	6215805.86	395.000	15736.217		

Tests of Between-Subjects Effects

Measure: HU

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	409898132	1	409898132	1437.541	.000
Group	1167574.59	1	1167574.59	4.095	.044
Error	112629651	395	285138.356		

Pairwise Comparisons

Measure: MEASURE_1

Group	(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
Control	1	2	51.502*	12.330	.000	27.261	75.744
	2	1	-51.502*	12.330	.000	-75.744	-27.261
Test	1	2	-16.011	12.870	.214	-41.313	9.292
	2	1	16.011	12.870	.214	-9.292	41.313

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Pairwise Comparisons

Measure: HU

Time	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	Control	Test	110.521*	39.029	.005	33.791	187.251
	Test	Control	-110.521*	39.029	.005	-187.251	-33.791
2	Control	Test	43.008	38.908	.270	-33.484	119.500
	Test	Control	-43.008	38.908	.270	-119.500	33.484

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Pairwise Comparisons

Measure: HU

(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	2	17.746*	8.912	.047	.225	35.267
2	1	-17.746*	8.912	.047	-35.267	-.225

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments)

Pairwise Comparisons

Measure: HU

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
Control	Test	76.765*	37.936	.044	2.184	151.345
Test	Control	-76.765*	37.936	.044	-151.345	-2.184

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Appendix K

Statistical Analysis for the Periotest value for target teeth (mobile teeth)

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Baseline PTV	Control	8.980	6.4878	55
	Test	11.861	7.3630	59
	Total	10.471	7.0733	114
Follow-up PTV	Control	8.953	6.3749	55
	Test	12.990	7.8940	59
	Total	11.042	7.4506	114

Tests of Within-Subjects Effects

Measure: PeriotestValue

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
TIme	Sphericity Assumed	17.270	1	17.270	1.920	.169	.017
	Greenhouse-Geisser	17.270	1.000	17.270	1.920	.169	.017
	Huynh-Feldt	17.270	1.000	17.270	1.920	.169	.017
	Lower-bound	17.270	1.000	17.270	1.920	.169	.017
TIme * Group	Sphericity Assumed	19.022	1	19.022	2.115	.149	.019
	Greenhouse-Geisser	19.022	1.000	19.022	2.115	.149	.019
	Huynh-Feldt	19.022	1.000	19.022	2.115	.149	.019
	Lower-bound	19.022	1.000	19.022	2.115	.149	.019
Error(TIme)	Sphericity Assumed	1007.465	112	8.995			
	Greenhouse-Geisser	1007.465	112.000	8.995			
	Huynh-Feldt	1007.465	112.000	8.995			
	Lower-bound	1007.465	112.000	8.995			

Tests of Between-Subjects Effects

Measure: PeriotestValue

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	26051.575	1	26051.575	285.534	.000	.718
Group	681.171	1	681.171	7.466	.007	.062
Error	10218.654	112	91.238			

Pairwise Comparisons

Measure: PeriotestValue

TIme	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	Control	Test	-2.881*	1.304	.029	-5.464	-.298
	Test	Control	2.881*	1.304	.029	.298	5.464
2	Control	Test	-4.037*	1.350	.003	-6.712	-1.363
	Test	Control	4.037*	1.350	.003	1.363	6.712

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Pairwise Comparisons

Measure: MEASURE_1

Group	(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
Control	1	2	.027	.572	.962	-1.106	1.160
	2	1	-.027	.572	.962	-1.160	1.106
Test	1	2	-1.129*	.552	.043	-2.223	-.035
	2	1	1.129*	.552	.043	.035	2.223

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Pairwise Comparisons

Measure: PeriotestValue

(I) TIme	(J) TIme	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	-.551	.397	.169	-1.338	.237
2	1	.551	.397	.169	-.237	1.338

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Pairwise Comparisons

Measure: PeriotestValue

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
Control	Test	-3.459*	1.266	.007	-5.967	-.951
Test	Control	3.459*	1.266	.007	.951	5.967

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Statistical Analysis for the Hounsfield Unit (HU) value or target teeth (mobile teeth):

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Baseline HU	Control	825.75	375.820	51
	Test	789.88	364.520	59
	Total	806.51	368.532	110
Follow Up HU	Control	808.35	347.392	51
	Test	769.68	376.367	59
	Total	787.61	362.089	110

Tests of Between-Subjects Effects

Measure: HounsfieldUnitValue

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	139500623	1	139500623	546.859	.000	.835
Group	75991.206	1	75991.206	.298	.586	.003
Error	27550192.5	108	255094.375			

Tests of Within-Subjects Effects

Measure: HounsfieldUnitValue

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Time	Sphericity Assumed	19331.801	1	19331.801	1.422	.236	.013
	Greenhouse-Geisser	19331.801	1.000	19331.801	1.422	.236	.013
	Huynh-Feldt	19331.801	1.000	19331.801	1.422	.236	.013
	Lower-bound	19331.801	1.000	19331.801	1.422	.236	.013
Time * Group	Sphericity Assumed	108.092	1	108.092	.008	.929	.000
	Greenhouse-Geisser	108.092	1.000	108.092	.008	.929	.000
	Huynh-Feldt	108.092	1.000	108.092	.008	.929	.000
	Lower-bound	108.092	1.000	108.092	.008	.929	.000
Error(Time)	Sphericity Assumed	1468467.86	108	13596.925			
	Greenhouse-Geisser	1468467.86	108.000	13596.925			
	Huynh-Feldt	1468467.86	108.000	13596.925			
	Lower-bound	1468467.86	108.000	13596.925			

Pairwise Comparisons

Measure: MEASURE_1

Group	(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
						Lower Bound	Upper Bound
Control	1	2	17.392	23.091	.453	-28.379	63.163
	2	1	-17.392	23.091	.453	-63.163	28.379
Test	1	2	20.203	21.469	.349	-22.352	62.758
	2	1	-20.203	21.469	.349	-62.758	22.352

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Pairwise Comparisons

Measure: HounsfieldUnitValue

(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	18.798	15.765	.236	-12.451	50.046
2	1	-18.798	15.765	.236	-50.046	12.451

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Pairwise Comparisons

Measure: HounsfieldUnitValue

Time	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
						Lower Bound	Upper Bound
1	Control	Test	35.864	70.704	.613	-104.284	176.012
	Test	Control	-35.864	70.704	.613	-176.012	104.284
2	Control	Test	38.675	69.451	.579	-98.989	176.339
	Test	Control	-38.675	69.451	.579	-176.339	98.989

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Pairwise Comparisons

Measure: HounsfieldUnitValue

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Control	Test	37.269	68.284	.586	-98.082	172.621
Test	Control	-37.269	68.284	.586	-172.621	98.082

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).