DIMENSIONAL SLOT INTEGRITY AND PRECISION OF SELF-LIGATING BUCCAL TUBES

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By
Yonatan Cohen, D.M.D.
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Thesis Approval(s):

Jeffrey H. Godel, D.D.S.
Thesis Advisor, Temple U. Kornberg School of Dentistry, Dept. of Orthodontics

Steven R. Jefferies, D.D.S., M.S., Ph.D
Committee Member, Temple U. Kornberg School of Dentistry, Dept. of Restorative Dentistry, Director of Biomaterials Research Laboratory

Sergio Real Figueroa, D.D.S., M.S.
Committee Member, Nova Southeastern University College of Dental Medicine, Dept. of Orthodontics

James J. Sciote, D.D.S., Ph.D
Committee Member, Temple U. Kornberg School of Dentistry, Dept. of Orthodontics

ABSTRACT

Self-ligating brackets, including molar buccal tubes, have gained popularity in recent decades. The primary advantage of using self-ligating systems has been based on the claim that they provide reduced friction and therefore reduced sliding resistance of the arch wire contained within their respective slots.[1] This form of reduced friction and sliding resistance has been proposed to require less force and therefore produce more physiologic tooth movements.[7-9] Limited scientific evidence is currently available to establish quality control of these products. The purpose of this study is to use Micro Computed Tomography (MicroCT) to analyze self-ligating molar tubes manufactured by different companies. Methods used here provide a novel way for measuring the accuracy and quality of these materials. This study has provided a highly innovative approach that had not been previously accomplished.

Forty self-ligating lower left first mandibular molar samples were obtained from four different companies. Five samples from each company were randomly selected and scanned using MicroCT to determine the internal slot lumen of each tube for analysis of precision volumetric measurements. Additionally, qualitative analysis of the lumen of each tube was investigated for the presence of any internal slot defects or imperfections.

Results showed that the volumetric slot measurements of all samples were highly statistically significant ($P<0.001$) and were found to be oversized compared to what is claimed by their respective companies. Qualitative analysis of all samples illustrated varying defects contained within their respective internal slot lumens. Notable defects

included notched, beveled and irregular corners, as well as the presence of some bulbous metal projections.

Based upon the results obtained in this study, it was determined that the investigated self-ligating buccal tubes, produced by all the companies tested, were oversized and had various internal slot defects. The potential clinical significance of these dimensional inaccuracies may include an increased amount of friction and a lack of torque control during tooth movement.

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Thank you Dr. Godel, Dr. Jefferies, Dr. Real and Dr. Sciote for all your guidance and support with this project. Dr. Real, thank you for allowing me to come on board two years ago to assist in your research project and peak my interest in this subject matter. A very special thank you goes to Mamta who aided me in conducting all the MicroCT scans and reconstructions of the samples investigated in this study. Thank you all for your dedication to my project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

The delivery of orthodontic care and the appliances used have greatly evolved over the past century. In 1928, Edward Angle introduced the original Edgewise appliance.[1] Angle emphasized non-extraction and in order to achieve an ideal occlusion with a full complement of teeth, each tooth must be positioned in its' ideal location within the arch. Furthermore, Angle chose an optimal bracket slot size of 0.022x0.028 inches in order to ensure proper distribution of forces to the dentition. During this time, orthodontists were required to make various bends of the arch wire to provide the necessary individual tooth movements into their ideal positions. These bends included: First-order (in and out) bends to achieve proper alignment, Second-order (tip) bends to ensure root parallelism, and Third-order (torque) bends to achieve proper facio-lingual inclination.

With time, newer treatment philosophies and approaches began to emerge. For example, Charles Tweed emphasized the importance of achieving better facial harmony and stability through the extractions of premolars and subsequent movement of teeth within basal bone.[1] Extraction space closure mechanics then gave rise to further varying treatment approaches. In order to reduce the amount of torqueing force applied to the dentition, a 0.018x0.025 inches bracket slot became another popular choice. This smaller bracket slot was used to allow smaller arch wires that could produce lighter forces, were easier to bend, and yet were large enough to “fill” these slots for achieving proper inclinations of the teeth.

In the 1960s, Lawrence F. Andrews established "six keys to normal occlusion" to provide orthodontists with guidelines in which to measure the static relationship of successful orthodontic treatment.[2] These six keys include: proper molar relationship, crown angulation (tip), crown inclination, lack of undesirable rotations, tight contacts, and relatively flat occlusal plane. For example, the distal surface of the distobuccal cusp of the upper first molar should occlude with the mesial surface of the mesiobuccal cusp of the lower second molar. Therefore, attending to these six keys served as the basis to what is considered the final desired occlusion, as well as led to the development of the first pre-adjusted appliance.[2,3]

The delivery of orthodontic care further evolved with the introduction of the Straight Wire Appliance (SWA). Rather than making numerous bends into an arch wire to provide individual tooth movements, brackets and buccal tubes are now manufactured with various slot prescriptions in order to express "pre-programmed" tooth movements. Therefore, the accuracy of these bracket slots is critical since the placement of a full size straight arch wire should theoretically express the ideal pre-determined positioning of teeth, greatly simplifying orthodontic treatment delivery.[3] A prescription SWA in this case refers to the manufacturers claims that a given bracket slot will have, for example, 11 degrees of tip and 7 degrees of torque compared to another prescription for the same tooth with 5 degrees of tip and 2 degrees of torque.

There are dozens of variations of these SWAs on the market today and the practitioner has the ability to mix and match. In addition, some brackets now have "self-ligating" features in which a sliding door or clip holds the respective arch wires within the slots versus conventional ligation. Thus, orthodontic brackets and treatment philosophies are currently marketed claiming that just a few degrees of variation within a given prescription may result in a better or more efficient treatment result.[3]

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Features of the Orthodontic Molar Tube

The designs of orthodontic fixed appliances have undergone persistent modifications since their initial use. Orthodontic brackets and tubes have multiple essential features including sufficient hardness and strength, smooth arch wire slot to reduce frictional resistance, and an overall smooth surface to minimize plaque accumulation. A molar tube generally consists of a pad, slot, hook, and other auxiliary attachments, such as a headgear tube that can be added as needed. In order to insert a straight arch wire into a tube, the pad is manufactured at an angle to the lumen of the tube. This angle determines the torque that is applied to the tooth for achieving the desired bucco-lingual inclination. In addition, the lumen of the tube is angulated to the pad in the mesio-distal direction to account for the buccal surface anatomy of the tooth and the curvature of the dental arches.

2.2 Self-ligating systems

Self-ligating brackets have regained popularity in recent decades following their initial development in the 1930s. As opposed to conventional brackets that require steel or elastomeric ligatures, self-ligating brackets utilize metal doors or clips to open and close their respective slots for engagement of the contained arch wire. There are two different types of self-ligating brackets, active and passive, based on their mechanisms of opening and closing. Active self-ligating brackets contain a spring clip that provides pressure against the arch wire. This form of self-ligation is proposed to provide additional torque and rotation control. On the other hand, passive self-ligating brackets use a door or slide that does not impinge the lumen space. Therefore, passive self-ligating brackets do not exhibit an active force against the contained arch wire.

The promotion of these bracket systems has provoked considerable debate in recent years. The primary advantage of using self-ligating brackets has been based on the claim that they provide reduced friction and therefore reduced sliding resistance of the arch wire contained within the respective bracket slot.[4-7] This form of reduced friction and sliding resistance has been proposed to require less force and therefore produce more physiologic tooth movements by not overpowering the musculature leading to interruption of periodontal vascular supply.[7,8] With more harmonious tooth movements, advocates emphasize these systems decrease the need for extractions by promoting more alveolar bone generation, greater amounts of expansion, and less proclination of anterior teeth.[9]

The most compelling advantages proposed by use of self-ligated brackets, opposed to conventional brackets, involve treatment efficiency.[10,11] In orthodontic treatment, factors that can potentially involve an increase in treatment efficiency include: shorter appointments, fewer appointments, easier technical procedures for clinician or assistant, and faster overall treatment time.[11] Therefore, lower resistance to sliding between brackets and arch wire, faster ligation and arch wire removal, and reduced chair time are among the core assets proposed for self-ligation. Some self-ligating brackets are promoted on the premise that elimination of conventional ligatures reduces friction and allows for faster sliding mechanics, which potentially reduces overall treatment time. However, self-ligating brackets also have some disadvantages that include higher cost, potential breakage of the clip or metal door, and difficulty in finishing due to incomplete expression of the arch wires.[12,13]

2.3 Friction

Friction is generated whenever a force is applied to bodies in contact and occurs in the opposite direction to the desired movement.[14] In clinical terms, any force applied to achieve a desired movement must exceed the inherent frictional force of the appliance.[15] There are numerous variables in a fixed appliance system that can influence the amount of friction produced including: saliva, bracket slot design and dimension, arch wire dimension, composition of brackets and arch wires, arch wire deflection, and the interbracket distance.[16]

Previous in-vitro studies have illustrated that less friction is generated with self-ligating brackets versus conventional brackets.[15,17-22] However, application of these laboratory results claiming that less force is required to produce the desired tooth movements in a clinical setting has not been fully addressed. The biology of tooth movement is a complex coordinated process that involves not only mechanical factors, but also biologic factors at the genetic, cellular, and molecular levels.[16] Therefore, it is unlikely that any single factor, such as reduced friction, translates into faster tooth movement, increased treatment efficiency, and decreased sliding resistance.[16]

2.4 Sliding Mechanics

The introduction of extraction treatment in orthodontics evolved into the use of different retraction mechanics for orthodontic space closure. The two major approaches are the use of closing loops and sliding mechanics. Practitioners that support the use of closing loops believe that this technique allows better control of tooth movement compared to sliding mechanics. However, the potential disadvantage of using closing loops involves the design, location, and management of the loop components, which some clinicians may find more complicated.

Since the introduction of the pre-adjusted straight wire appliance, the use of sliding mechanics has become a popular alternative for space closure. These mechanics involve the ability of the arch wire to move through the bracket slots and buccal tubes in order to retract an individual tooth or group of teeth with the wire. An example of these mechanics can be illustrated following the extractions of first premolars, in which the canines are initially retracted along the arch wire followed by retraction of the four incisors together to close the spaces provided by the extractions. In order to achieve extraction space closure with limited side effects, the forces acting on the anterior portion of the arch wire during retraction of incisors would allow the excess wire to slide through the posterior brackets and tubes. Therefore, the presence of any friction along the posterior segments of the appliance could potentially hinder the free movement of the wire and hence delay tooth movement and overall treatment.[23,24] Clinicians will often use wires of smaller dimensions to minimize any excessive friction during space closure, however, the use of these smaller wires limits the practitioners ability to control second and third order tooth movements.

2.5 Effect of Bracket Type on Orthodontic Space Closure

Previous studies have attempted to investigate the influence of bracket type during orthodontic space closure.[14, 25,26] These studies were conducted to compare self-ligating systems versus conventional brackets with respect to the amount and rate of space closure in the clinical setting.

Wong et al[25] performed a random clinical trial using 45 total patients, of which 15 were randomly allocated to each subgroup including conventional brackets with standard elastomeric ligation, conventional brackets with reduced friction elastomeric ligation, and self-ligated brackets. Orthodontic space closure was measured at 4 week intervals for 3 months using full arch treatment, with the following mean results: conventional brackets with standard or reduced friction elastomers = 3.0mm (1.0mm per month); self-ligated brackets = 2.7mm (0.9mm per month). However, methods performed in this study may have resulted in confounding limitations not accounted for previously. For example, all participants had conventional first molar buccal tubes despite being individually assigned to the conventional or self-ligating subgroups. Therefore, the amount and rate of orthodontic space closure was confounded due to the fact that the arch wire requires sliding through the buccal tubes as well. This has the potential to result in varying friction and sliding resistance, which should have been addressed by using self-ligating tubes on the first molar teeth for the patients in the self-ligating subgroup.

Mezomo et al[14] conducted a random clinical trial using a small sample size of 15 patients. Patients were treated with orthodontic space closure using a split mouth design, in which random allocation of self-ligated brackets were placed on only canine teeth to be used for space closure. Orthodontic space closure was measured at 4 weekly intervals for 3 months with the following results: conventional brackets = 2.53mm (0.84mm per month); self-ligating brackets = 2.68mm (0.90mm per month).

Miles[26] performed a controlled clinical trial using a split mouth design, of which conventional or self-ligating brackets were placed on only second premolar teeth. A small sample size and 22% withdrawal of participants yielded the following results for the 13 included patients: conventional brackets = 1.2mm per month; self-ligating brackets = 1.1mm per month.

The Mezomo et al[14] and Miles[26] studies are both limited by confounding variables. For example, the split mouth study design was performed in both studies. The potential confounding factor that applies to any split mouth design is that the arch wire can slide to one side and therefore effect the friction and binding during tooth movement on the opposite side. Furthermore, only the canine tooth was selected for placement of a self-ligating bracket in the Mezomo et al[14] study, while the 2nd premolar tooth was the only tooth used for the self-ligating bracket in the Miles[26] study. Therefore, the role of friction and sliding resistance in orthodontic space closure was not accurately evaluated for self-ligated brackets compared to conventional brackets.

The final confounding factor identified was the differing methods of space closure between the three studies described above. For example, retraction was provided using

NiTi springs in the studies performed by Wong et al[25] and Miles[26]. This form of space closure provides a continuous light retraction force without the role of friction or sliding resistance added to the overall mechanics involved. On the other hand, the use of elastomeric power chain was used in the Mezomo et al[14] study. The retraction force of the elastic module not only diminishes greatly on a daily basis, but also provides additional friction and resistance to sliding. In addition, this power chain was placed over the arch wire and self-ligating brackets despite the fact that if used with self-ligation appliances, elastomeric chains should be placed under the arch wire to avoid producing additional resistance or friction.

Although all three of the studies described above reported insignificant differences between orthodontic space closure using self-ligating and conventional brackets, a conclusion that faster overall space closure could be done with self-ligated brackets was neither supported or rejected based upon the quality of the scientific evidence presented. Confounding variables in each study limited interpretation of measured outcomes. Therefore, future research is clearly needed to accurately assess the comparisons in orthodontic space closure using self-ligated appliances versus conventional appliances. These proposed studies should consist of random controlled clinical trials, which are performed with a low risk of bias and are conducted using an appropriate sample size. Patients in these studies should be treated using a full mouth study design with consistent use of either conventional brackets or self-ligated brackets and not a mixture of both. In addition, the use of space closure mechanics should consist of NiTi retraction springs or elastomeric power chain that is placed under the arch wire in an attempt to limit any potential effects of additional friction.

2.6 Accuracy of slot dimensions

The slot dimensional accuracy is critical in order to produce the prescribed three-dimensional tooth movements through delivery of an optimized force between engagements of the wire within the respective slot. Previous studies have illustrated the impact on orthodontic treatment due to variations in bracket slots and arch wire sizes.[23, 24,27-35] The studies conducted by Kusy et al[28], Cash et al[31], and Brown et al[32] analyzed the bracket slot dimensions in various incisor, canine, or premolar brackets. These studies concluded that the brackets observed were inaccurate. Kusy et al[28] and Cash et al[31] illustrated that the majority of brackets were oversized up to 24%, while Brown et al[32] found their samples to be approximately 20% undersized and 16% oversized. An undersized molar tube may cause friction during orthodontic space closure. The use of an oversized molar tube could potentially result in excessive buccal or lingual inclination and marginal ridge discrepancies caused by improper expression of the prescribed tooth movements including both tip and torque. Resolving these negative outcomes involves customizing arch wires, which requires additional chair time and total treatment time.

Although previous studies have been conducted regarding bracket slot dimensions of incisors, cuspids, and bicuspids, only one study to date has attempted to analyze conventional molar tubes (not self-ligating tubes).[30] In addition, previous studies utilized light or scanning electron microscopy to evaluate their respective samples.[30-35] These methods failed to directly address slot taper/wall parallelism, the rounded or beveled edges contained within slots, and analyze the critical aspects of the internal slot walls.[35] The internal aspects of a buccal tube contain several millimeters that provide the majority of contact with the respective arch wire used. Therefore, orthodontic buccal tubes may contain internal dimensional inaccuracies and defects, the presence of which may lead to adverse treatment outcomes.

2.7 Micro-computed Tomography (micro-CT)

X-ray micro-CT has emerged with the promise of providing 3D structural information that previously was inaccessible by standard 2D imaging analysis.[36] The development of this technology along with the accompanying SkyScan software (NRecon, Data Viewer, CTAn, and CTVox) allows an investigator to achieve high resolution three-dimensional reconstructions, image processing, and 3D analysis of the samples or specimens of interest for accurate analyses of both qualitative and quantitative information. Previous studies have utilized micro-CT to quantify the microvasculature in lung tumors as well as for 3D reconstruction and quantitative analysis of neovasculature in xenografted tumors.[36] This method offers more thorough structural characterization of samples of interest than 2D image analysis such as Scanning Electron Microscopy. The time for the overall procedure can range from a few days up to one week, depending on several factors, including the size of each specimen, numbers of specimens, and the processing speed of the computer running the software.[36] In addition, micro-CT scanning can be left to run overnight. Multiple samples can be scanned in a single (partitioned) scanning procedure. This can be accomplished by layering the samples within the scanning tube as long as they do not overlap across the horizontal plane.[36]

CHAPTER 3

AIMS OF THE INVESTIGATION

The overall aim of this study is to establish a new standard for measuring the accuracy and quality of orthodontic brackets and molar buccal tubes. Specific aims include:

- To measure the size and surface features within the slots of self-ligating tubes using 3-dimensional Micro-computed Tomography. Measurements will be analyzed with CTAn software that reconstructs cross sectional slices and segments of regions of interest. Volumes of the internal slot lumens will be quantitatively analyzed for their prescribed accuracy.

- To use the volumetric slot measurements determined by micro-CT for evaluation of accuracy within ADA standard parameters (0.0225 x 0.0285 inches)[38] claimed to be acceptable by four different bracket manufacturers.

- To determine the presence of any internal slot defects or imperfections. CTVox software, which enables visualization of 3D volumes from reconstructed cross sections, will be used for this qualitative analysis of internal slot lumens.

CHAPTER 4

MATERIALS & METHODS

Micro-CT has been used for the study of organic materials including: bone, tissue, and tumors. To the knowledge of the investigator, micro-CT had never been utilized for the analysis of dense metal objects. Following the training process of how to properly use the micro-CT and all accompanying software, the next step was to determine how to scan dense metal. Manufacturers of the micro-CT were doubtful such a procedure could be accomplished, as it had never been done to their knowledge before. However, a standardized scanning procedure was generated, through trial and error, by using differing scanning parameters, such as accelerating voltage, current, camera size, exposure time, and various filters.

The next step was to determine at which points to begin and end the internal slot measurements. Initially, we attempted to score points of reference, using a ¼ inch round bur into two different non-critical walls. However, this proved to be unnecessary since the internal slot and external tube geometry of the samples varies between those produced by different manufacturers. Therefore, the most consistent method for obtaining the first and last slot measurements were determined as the initial (upper vertical limit) and final (lower vertical limit) visualization all four slot walls.

How to take precision measurements of the lumen space despite irregular corners, tapered or bulbous walls, and varying internal geometry rather than being straight and rectangular, required generating Regions of Interest (ROI). Adjusting these ROI's and the histogram gray scale was accomplished to illustrate and analyze each lumen space to be black and surrounding metal to be white. Although not perfect, it permitted the ability to take accurate measurements with <5% error.

The final technological hurdle to overcome was accounting for differing slot lengths/depths and converting a 2D standard of 0.0225x0.0285 inches into a 3D volumetric standard to be used as the control. In order to tackle this variable, we determined the most consistent method for slot analysis was to compare each samples slot volume to its own adjusted volumetric control based on each individual slot length.

As stated above, no studies have used micro-CT to analyze orthodontic molar buccal tubes. In addition, previous studies used varying sample sizes for measuring different brackets or buccal tubes. Generally, these studies had randomly selected 5 incisor brackets from an average of 10 or 11 total brackets from each company examined. Therefore, an initial pilot study was conducted in order to determine the number of samples required to obtain statistical significance. This preliminary sample consisted of 5 self-ligating tubes purchased from the same company (Ormco – Damon system) and all lower left first mandibular molar tubes with the same prescription and slot size (022 MBT) to minimize any confounding variables and to maintain consistency. Each sample was positioned in a holder using parafilm and scanned by micro-CT (SkyScan 1172 DataViewer software; Skyscan, Aartselaar, Belgium) with 11 megapixel resolution. The scanning parameters were: accelerating voltage of 100 kV, current of 100 μA, medium camera size, exposure time of 855 ms per frame, Al + Cu filter, frame average of 8, and rotation step at 0.4 (180° rotation). The image pixel size was 6 μm.

Following the scanning step, 3D reconstruction by SkyScan's volumetric software, NRecon, can be conducted overnight as well. However, each sample must be reconstructed separately, which takes approximately 1-3 hours per sample.[36] Data Viewer, a program that displays reconstructed slices as intersecting orthogonal sections in x, y, and z planes, can be used to align and re-orient the samples of interest as well as to quantify the distances between structures.[37] CTAn, an analysis program, can be used to view the reconstructed cross sectional slices, to segment regions and volumes of interest, for 2D and 3D quantitative analysis, and to create 3D models.[36,37] Finally, CTVox is a 3D volume-rendering program that can be used to visualize the reconstructed cross sections in 3D for qualitative analysis of any defects or imperfections.[37] Following scanning and analysis of the samples, a one way ANOVA was conducted comparing the volumetric slot measurements to the ADA acceptable parameters of 0.0225 x 0.0285 inches, which yielded highly statistically significant results ($p<0.001$). These values were included in the remaining study.

40 lower left first mandibular molar self-ligating buccal tubes with 022 slot were purchased from four different companies (10 from each company): Ormco – Damon system, American Orthodontics – Empower, GAC International – In-Ovation system, and Forestadent – BioQuick system. Five samples from each company were randomly selected for scanning. The X-ray projections of each sample were reconstructed using SkyScan's volumetric reconstruction software (NRecon) that uses the set of acquired angular projections to create a set of cross section slices through the object. This program uses a modified Feldkamp algorithm with automatic adaptation to the scan geometry in each micro-CT scanner. Reconstructed slices were saved as a stack of bmp-

type files. Beam hardening correction of 40% and ring artifact correction of 10 were used for the reconstruction.

The Skyscan DataViewer software was then used to align and orient each sample in order to generate transaxial images in a consistent plane of space for all samples studied (Figure 1).

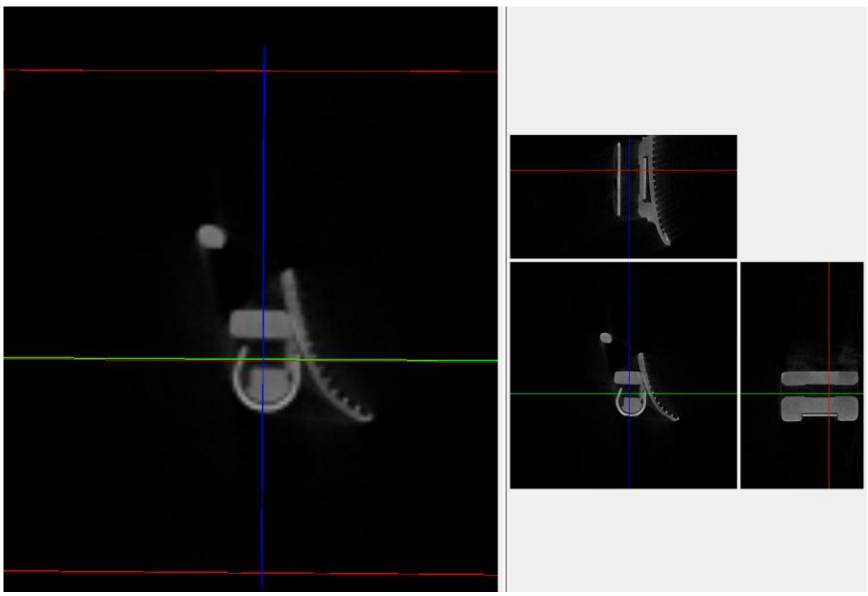


Figure 1: DataViewer software for alignment and orientation of samples in consistent planes in space.

Each respective dataset of transaxial images were then imported via the CTAn software to obtain cross-section images. These cross-sections were obtained by first selecting the upper and lower vertical limits for each respective internal slot lumen to be analyzed. Utilizing the CTAn software enabled the investigator to generate “Regions of Interest (ROI)” from which precision volumetric measurements were taken throughout the internal slots (Figure 2).

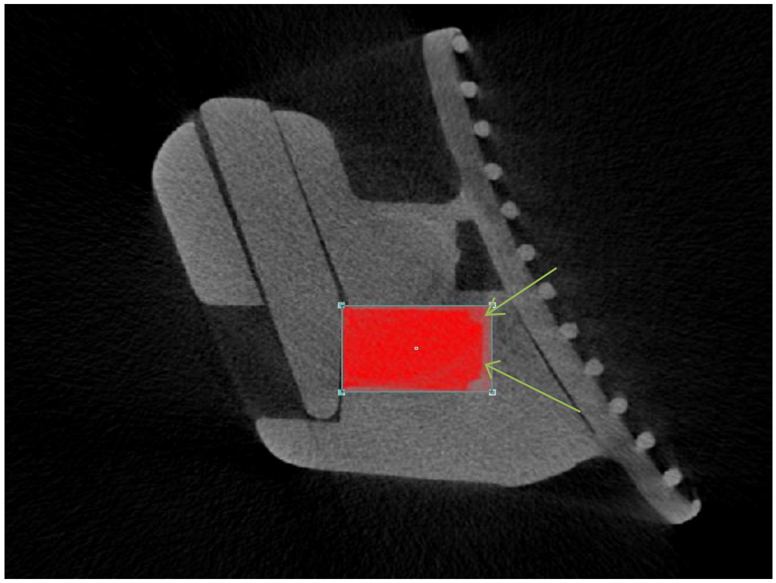
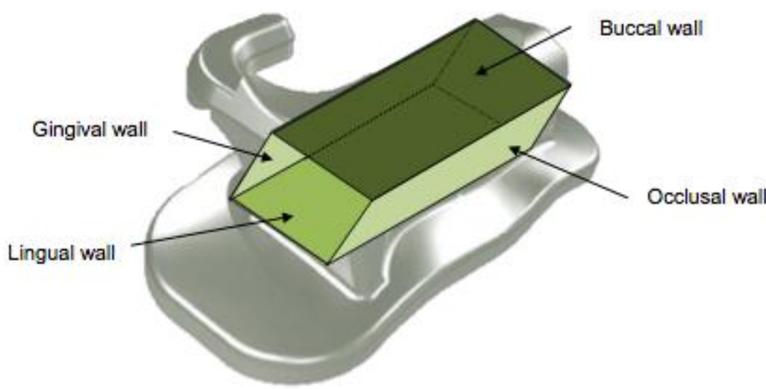
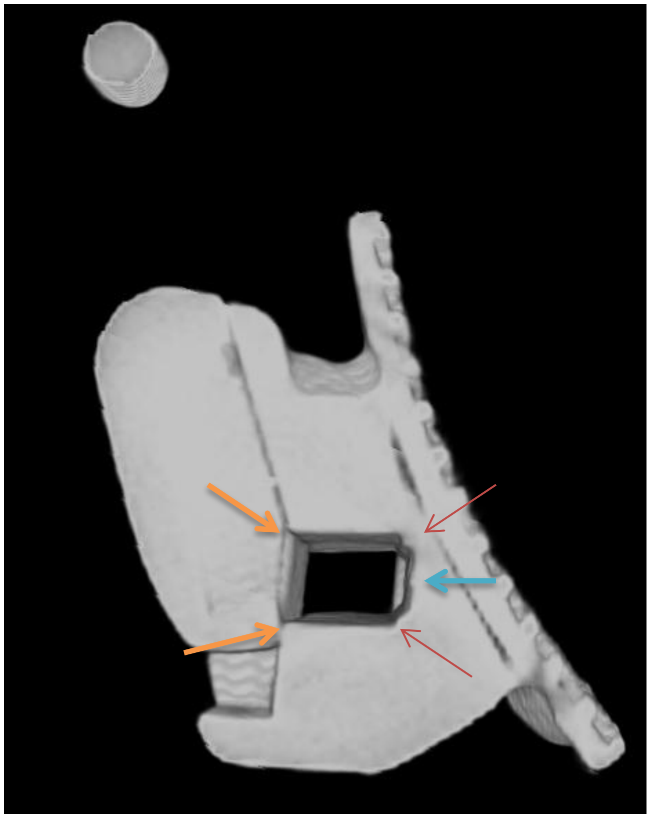


Figure 2: Region of Interest (ROI) seen in red. Precision volumetric measurements obtained by subtracting the Total Volume (TV – volume within red ROI) minus the Object Volume (OV – volume of white metal (arrows) within the red ROI) equals the volume of occupied space (slot lumen). Illustration below depicts the 3-dimensional volume obtained by ROI's – width, height, and length/depth.



These ROI's were analyzed with gray-scale threshold levels of 58 to 255. Precision volumetric measurements were calculated by subtracting the Total Volume (TV; the volume within the red ROI) minus the Object Volume (OV; volume of white metal within the red ROI), equals the volume of each respective internal slot lumen ("Slot

Volume”). In addition, the use of this software provides a novel approach for qualitative analysis for detection of any defects or imperfections contained within these internal slot lumens (Figures 3 and 4).



Types of Internal Wall Slot Defects

Term	Description
Bevel (→)	Corner of 2 walls that meet at an angle greater than a right angle
Notch (→)	V-shaped corner projecting into the lumen space
Bulbous metal projection(←)	Ovoid or spherical obstruction extending from a wall into the lumen space

Figure 3: Example of internal wall slot defect illustrated in MicroCT image of Ormco – Damon system sample. The defects are located along the vertical wall on the right side of the slot lumen as well as the upper and lower right corners, which are irregular, beveled, and notched.

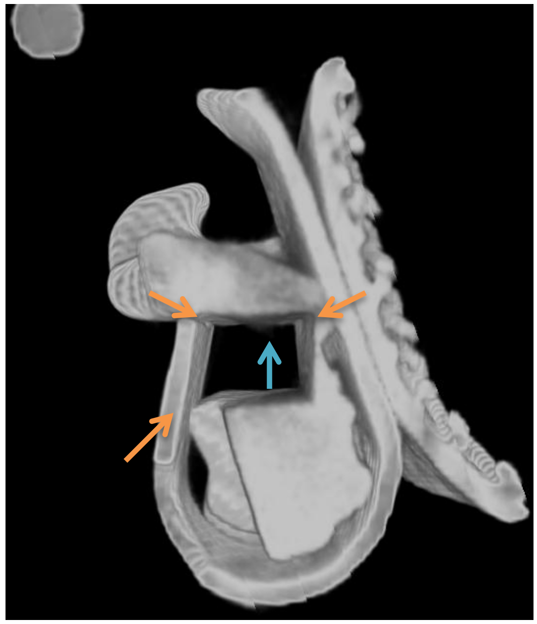


Figure 4: Example of internal wall slot defect illustrated in MicroCT image of American Orthodontics – Empower system. The defects vary and are generally located along the bottom horizontal, top horizontal, and vertical walls on the right side of the slot lumen. In addition these walls were highly irregular and bulbous shaped rather than straight and rectangular.

Slot volumes were compared to the ADA standards[38] as a control for acceptable parameters (0.0225 x 0.0285 inches x *total internal slot length inches*) to determine if variations exist amongst those produced by the same manufacturing companies. The total number of slices and total internal slot lumen length analyzed varied based on the overall length of each sample. The total internal slot length (inches) for each sample was calculated by subtracting the upper vertical limit minus the lower vertical limit. The acceptable parameters used as the control for dimensional accuracy analysis, were converted into volumetric dimensions by multiplying the 0.0225 x 0.0285 inches times each individual samples' total internal lumen length (in inches) analyzed. This value was labeled as the "adjusted volumetric parameters for control" (Appendix A).

4.1 Statistical Analyses

All data was collected and recorded on an Excel spreadsheet. Using parametric statistical analysis: descriptive statistics means and standard deviations were calculated for all four companies. In the first analysis, a 1-way ANOVA comparing the mean "difference" values was performed using a level of significance of 0.05. In the second analysis, unpaired T-tests were conducted to determine if any two companies were significantly different than each other.

CHAPTER 5

RESULTS

5.1 Establishing a standard

In order to create this innovative approach, several technological hurdles required months of initial work to overcome. These hurdles included: training in software use (scanning, NRecon, etc), establishing parameters for how to scan dense metal, standardizing the scanning procedure of where to begin and end slot analysis, determining how to measure the lumen space, how to account for differing slot lengths, and converting a 2D standard (0.0225x0.0285) into a 3D standard.

5.2 Slot dimensional accuracy

In order to properly analyze the slot dimensional accuracy of the orthodontic self-ligating tubes used in this study, each sample's "slot volume" was compared to the respective "adjusted volumetric parameters used for control" (Figure 5). These values were labeled as "Difference" and were calculated by subtracting the respective individual slot volume from its' corresponding adjusted control parameters (Appendix B).

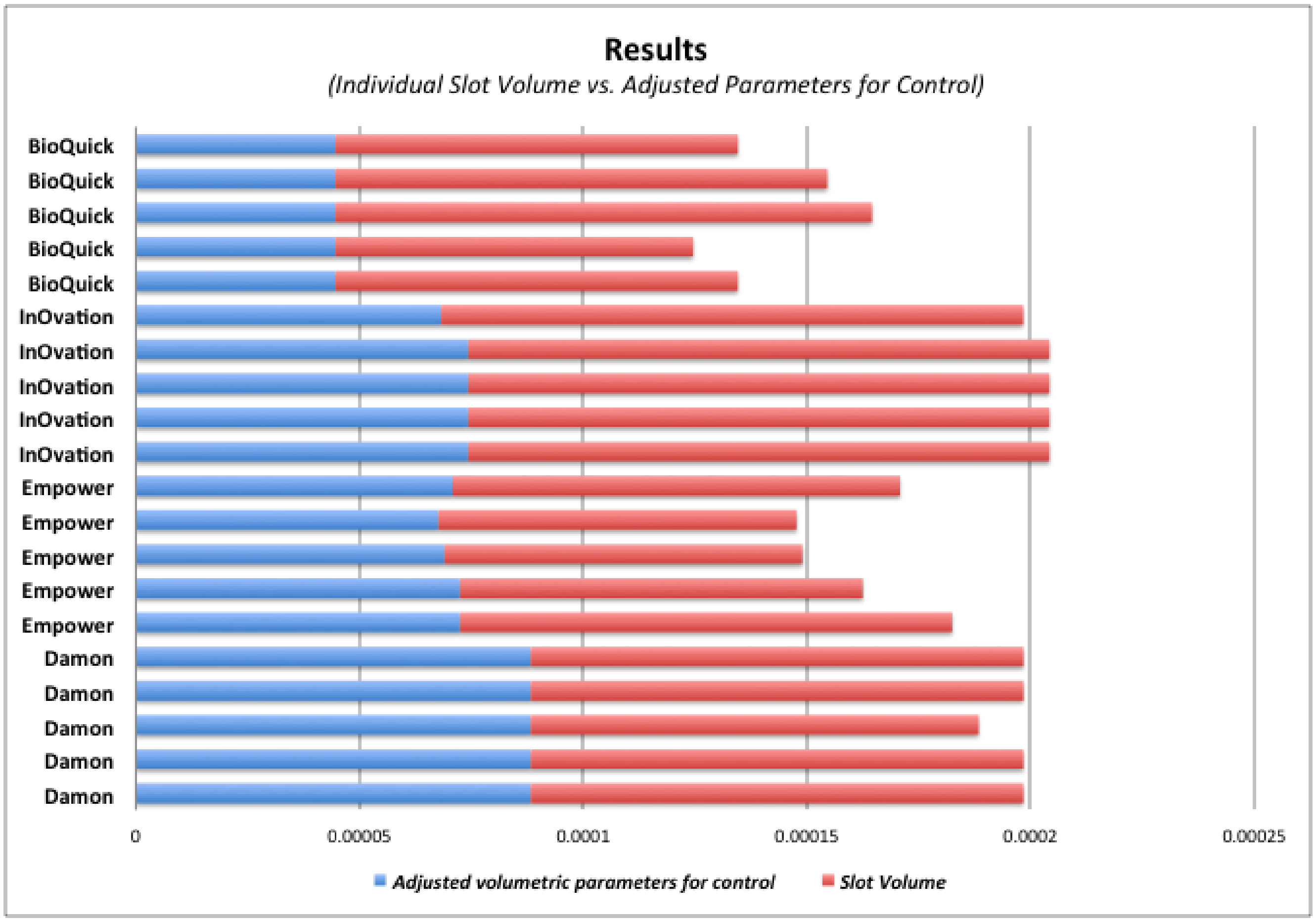


Figure 5: Graph of each samples results. Illustrates each individual slot volume and their respective adjusted parameters used for control (all values in cubic inches).

Descriptive statistics of all four companies investigated yielded varying differences between the slot volumes measured and what was determined as their respective acceptable parameters (Table 1). In the first analysis, a 1-way ANOVA (Table 2) comparing the mean "difference" values was performed and yielded highly significant results ($P<0.001$). As depicted by figure 6, all four companies manufactured self-ligating tubes with over-sized slot lumens. Ormco – Damon system produced samples that were the closest to the acceptable parameters with mean volumetric difference value of 1.97E-05 inches (SD = 4.47E-06). American Orthodontics – Empower produced samples with mean volumetric difference value of 2.15E-05 inches (SD = 1.15E-05). On the other hand, GAC – InOvation system produced tubes with the largest slot lumens compared to the acceptable parameters with mean volumetric difference of 5.70E-05 inches (SD = 2.65E-06). Finally, Forestadent – BioQuick system produced tubes with mean volumetric difference value of 5.35E-05 inches (SD = 1.64E-05).

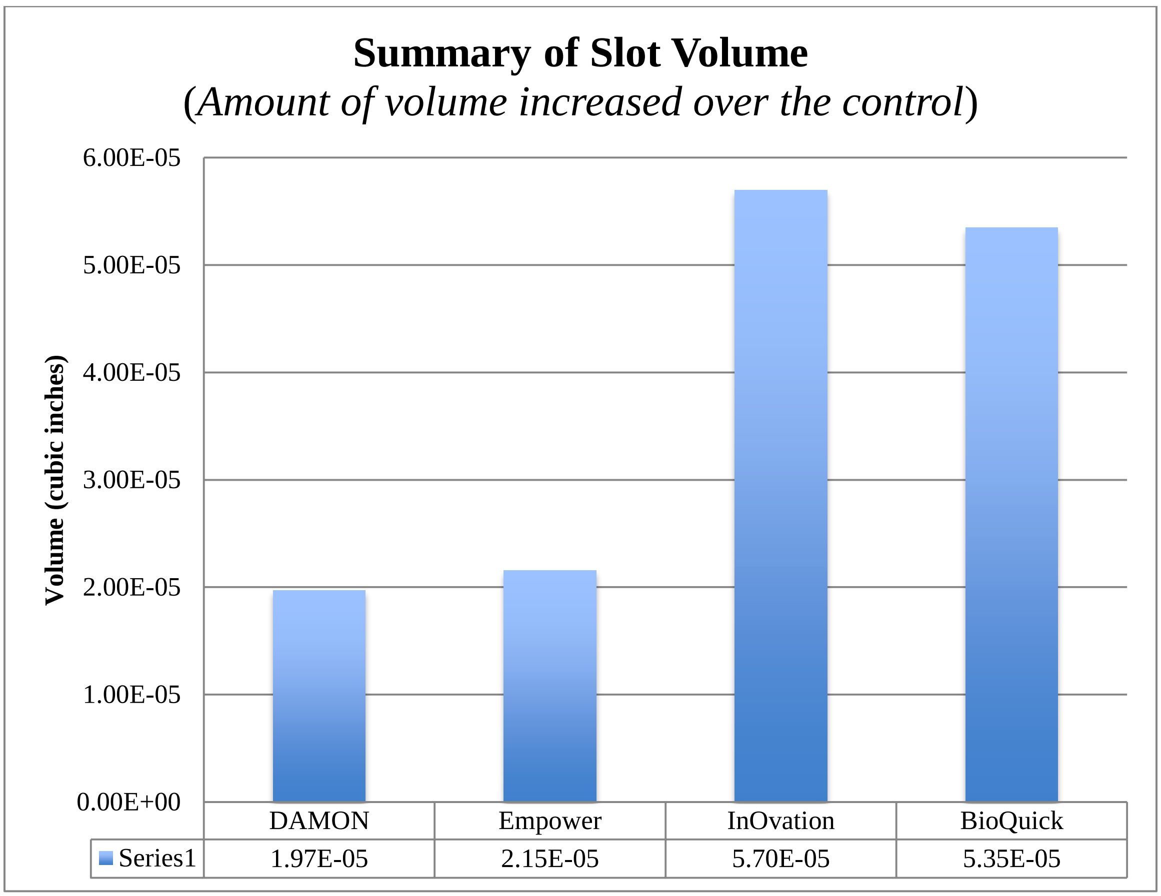


Figure 6: Summary of Slot Volume. This graph depicts each company's average difference in slot volume compared to the adjusted acceptable parameters (should be 0).

Table 1: SUMMARY of Descriptive Statistics

Groups	*Count*	*Sum*	*Average*	*Variance*	*SD*
DAMON	5	9.85E-05	1.97E-05	2.00E-11	4.47E-06
Empower	5	1.08E-04	2.15E-05	1.32E-10	1.15E-05
InOvation	5	2.85E-04	5.70E-05	7.05E-12	2.65E-06
BioQuick	5	2.67E-04	5.35E-05	2.70E-10	1.64E-05

Table 2: Results from a One-way ANOVA comparing mean "Difference" values.

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6.03E-09	3	2.01E-09	1.87E+01	1.74E-05	3.24E+00
Within Groups	1.72E-09	16	1.07E-10			
Total	7.75E-09	19				

*All manufacturers produced samples with over-sized slot lumens compared to the adjusted volumetric acceptable parameters.

In the second analysis, unpaired T-tests (Tables 3-8) were conducted to determine if any two companies were significantly different than each other ($P<0.05$ was considered significant). Results of this analysis illustrated highly significant differences exist between InOvation vs. Empower (Table 4), InOvation vs. Damon (Table 5), Empower vs. BioQuick (Table 7), and Damon vs. BioQuick (Table 8). According to table 4, InOvation vs. Empower analysis yielded highly significant results with P(T<=t) two tail = 1.49E-04. According to table 5, InOvation vs. Damon analysis yielded highly significant results with P(T<=t) two tail = 2.30E-07. According to table 7, Empower vs. BioQuick analysis yielded significant results with P(T<=t) two tail = 7.38E-03. According to table 8, Damon vs. BioQuick analysis yielded significant results with P(T<=t) two tail = 2.18E-03.

Table 3: Unpaired t-test comparing Damon vs. Empower

t-Test: Two-Sample Assuming Equal Variances

	DAMON	*Empower*
Mean	1.97E-05	2.15E-05
Variance	2.00E-11	1.32E-10
Observations	5	5
Pooled Variance	7.60E-11	
Hypothesized Mean Difference	0	
Df	8	
t Stat	-3.33E-01	
P(T<=t) one-tail	3.74E-01	
t Critical one-tail	1.86E+00	
P(T<=t) two-tail	7.47E-01	
t Critical two-tail	2.31E+00	

Table 4: Unpaired t-test comparing InOvation vs. Empower

t-Test: Two-Sample Assuming Equal Variances

	InOvation	*Empower*
Mean	5.70E-05	2.15E-05
Variance	7.05E-12	1.32E-10
Observations	5	5
Pooled Variance	6.95117E-11	
Hypothesized Mean Difference	0	
Df	8	
t Stat	6.72E+00	
P(T<=t) one-tail	7.46E-05	
t Critical one-tail	1.86E+00	
P(T<=t) two-tail	1.49E-04	
t Critical two-tail	2.31E+00	

Table 5: Unpaired t-test comparing InOvation vs. Damon

t-Test: Two-Sample Assuming Equal Variances

	InOvation	*DAMON*
Mean	5.70E-05	1.97E-05
Variance	7.05E-12	2.00E-11
Observations	5	5
Pooled Variance	1.35E-11	
Hypothesized Mean Difference	0	
Df	8	
t Stat	1.60E+01	
P(T<=t) one-tail	1.15E-07	
t Critical one-tail	1.86E+00	
P(T<=t) two-tail	2.30E-07	
t Critical two-tail	2.31E+00	

Table 6: Unpaired t-test comparing InOvation vs. BioQuick

t-Test: Two-Sample Assuming Equal Variances

	InOvation	*BioQuick*
Mean	5.70E-05	5.35E-05
Variance	7.05E-12	2.70E-10
Observations	5	5
Pooled Variance	1.39E-10	
Hypothesized Mean Difference	0	
Df	8	
t Stat	4.71E-01	
P(T<=t) one-tail	3.25E-01	
t Critical one-tail	1.86E+00	
P(T<=t) two-tail	6.50E-01	
t Critical two-tail	2.31E+00	

Table 7: Unpaired t-test comparing Empower vs. BioQuick

t-Test: Two-Sample Assuming Equal Variances

	Empower	*BioQuick*
Mean	2.15E-05	5.35E-05
Variance	1.32E-10	2.70E-10
Observations	5	5
Pooled Variance	2.01E-10	
Hypothesized Mean Difference	0	
Df	8	
t Stat	-3.56E+00	
P(T<=t) one-tail	3.69E-03	
t Critical one-tail	1.86E+00	
P(T<=t) two-tail	7.38E-03	
t Critical two-tail	2.31E+00	

Table 8: Unpaired t-test comparing Damon vs. BioQuick

t-Test: Two-Sample Assuming Equal Variances

	DAMON	*BioQuick*
Mean	1.97E-05	5.35E-05
Variance	2.00E-11	2.70E-10
Observations	5	5
Pooled Variance	1.45E-10	
Hypothesized Mean Difference	0	
Df	8	
t Stat	-4.44E+00	
P(T<=t) one-tail	1.09E-03	
t Critical one-tail	1.86E+00	
P(T<=t) two-tail	2.18E-03	
t Critical two-tail	2.31E+00	

5.3 Qualitative Analysis

In order to determine the presence of any internal slot defects or imperfections, the CTVox software, a 3D volume-rendering program, was utilized for observing the reconstructed cross sections of the respective samples. All samples illustrated varying defects contained within their respective internal slot lumens. Notable defects included notched, beveled and irregular corners, as well as the presence of some bulbous metal projections. In addition, some walls were irregular and bulbous shaped rather than straight and rectangular.

The Ormco – Damon system illustrated the consistent presence of highly irregular, beveled and notched corners among all samples investigated (Figures 7-11). In addition, sample #2 (Figure 8) also contained an irregular metal projection located approximately midway along it's right side vertical wall.

The American Orthodontics – Empower samples (Figures 12-16) all depicted varying defects that were generally located along the horizontal walls and right side vertical wall of their lumen spaces. These walls were highly irregular and bulbous shaped rather than straight and rectangular. In addition, other notable defects included: beveled corners and a bulbous metal projection located in the middle of the bottom horizontal wall of sample #1 (Figure 12) and top horizontal wall of sample #5 (Figure 16).

The five different samples investigated among GAC – InOvation system illustrated irregular, beveled corners generally located in the upper and lower right corners of the respective slot lumens (Figures 17-21).

The Forestadent – BioQuick system samples (Figures 22-26) all contained several millimeters of internal slot length that were excessive in overall size and would yield no significant engagement of any selected rectangular arch wire. As shown in sample #3 (Figure 24), only the most mesial and distal aspects of these tubes are capable of providing any wire engagement. In addition, other notable defects found within this group included: beveled corners, bulbous right vertical walls (samples #1 and #3), and bulbous horizontal walls (samples #1,4, and 5).

5.3.1 ORMCO – DAMON System

MicroCT Images of Defects

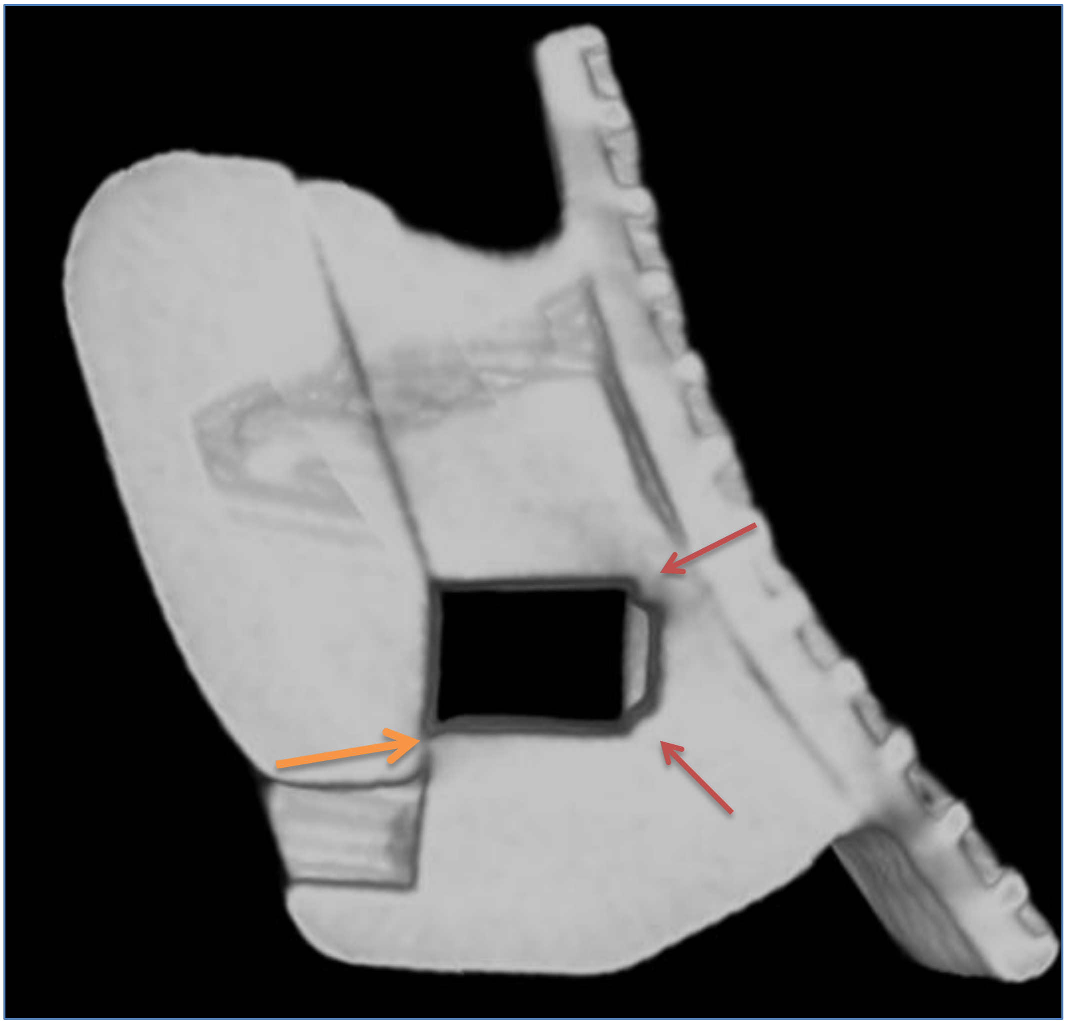


Figure 7: Sample #1 illustrates notched (←) and irregular, beveled (→) corners.

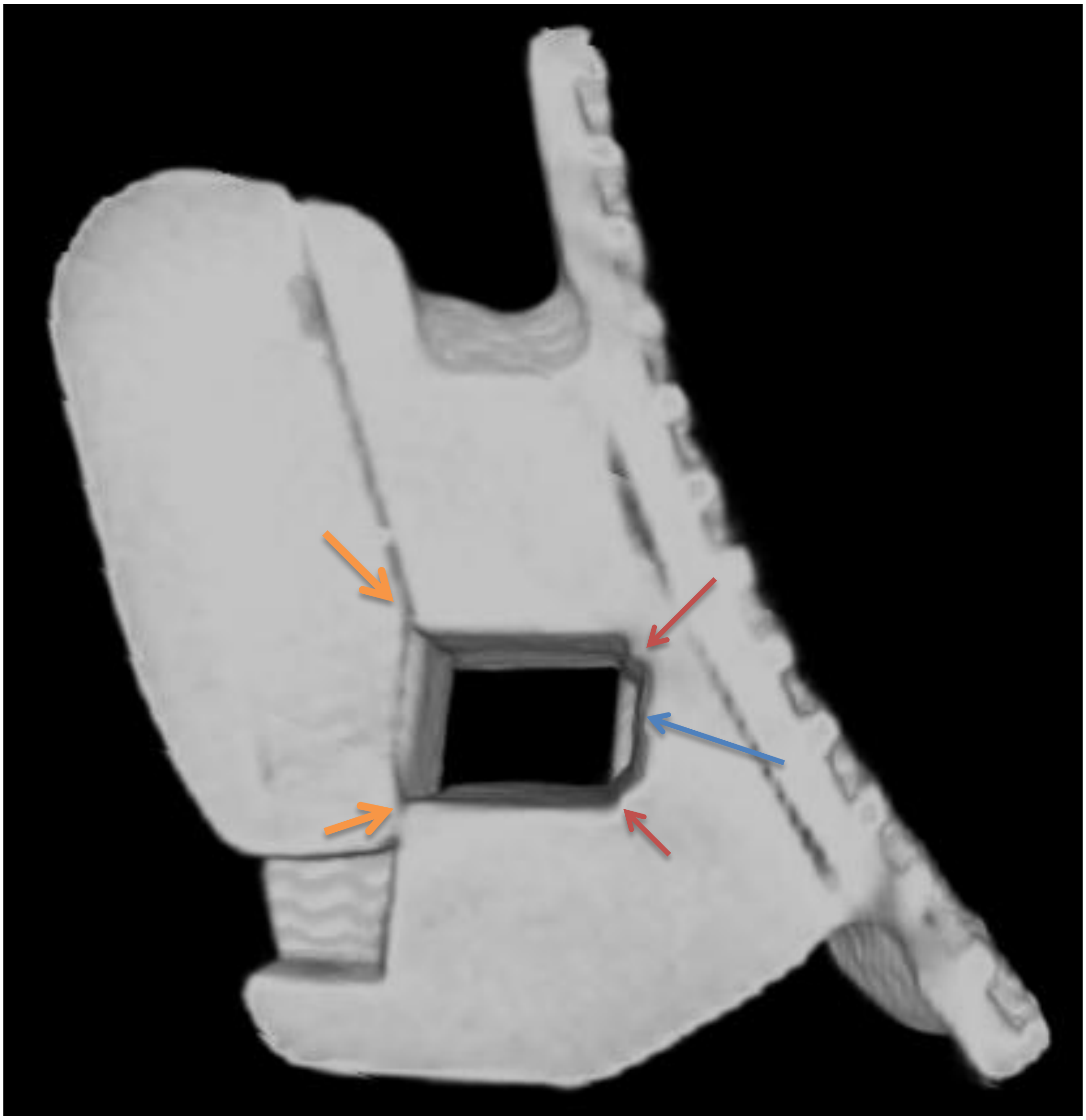


Figure 8: Sample #2 illustrates notched (←) and irregular, beveled (➔) corners. In addition, this sample contains a bulbous metal projection along the vertical wall (←——).

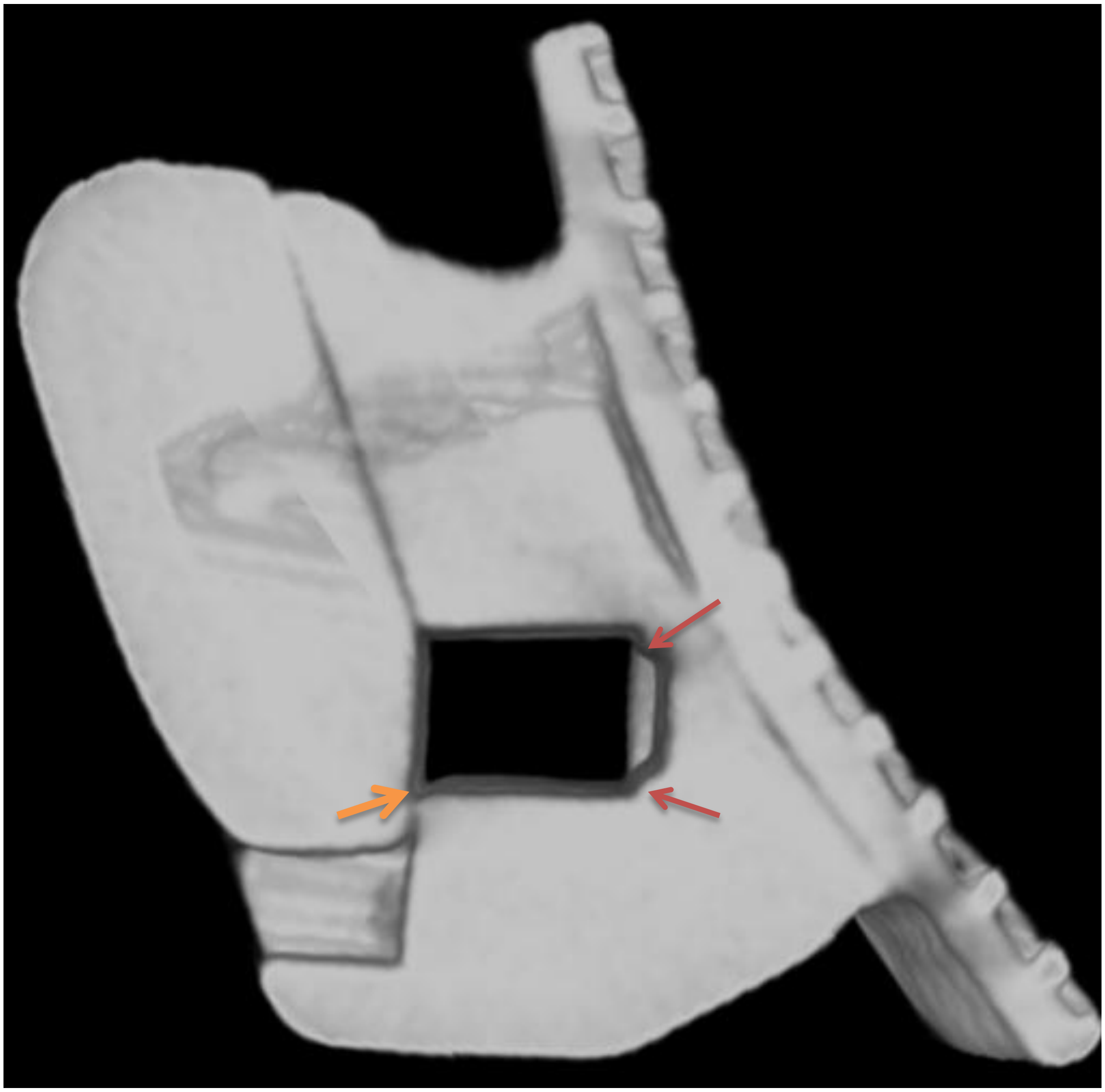


Figure 9: Sample #3 illustrates notched (←) and irregular, beveled (→) corners.

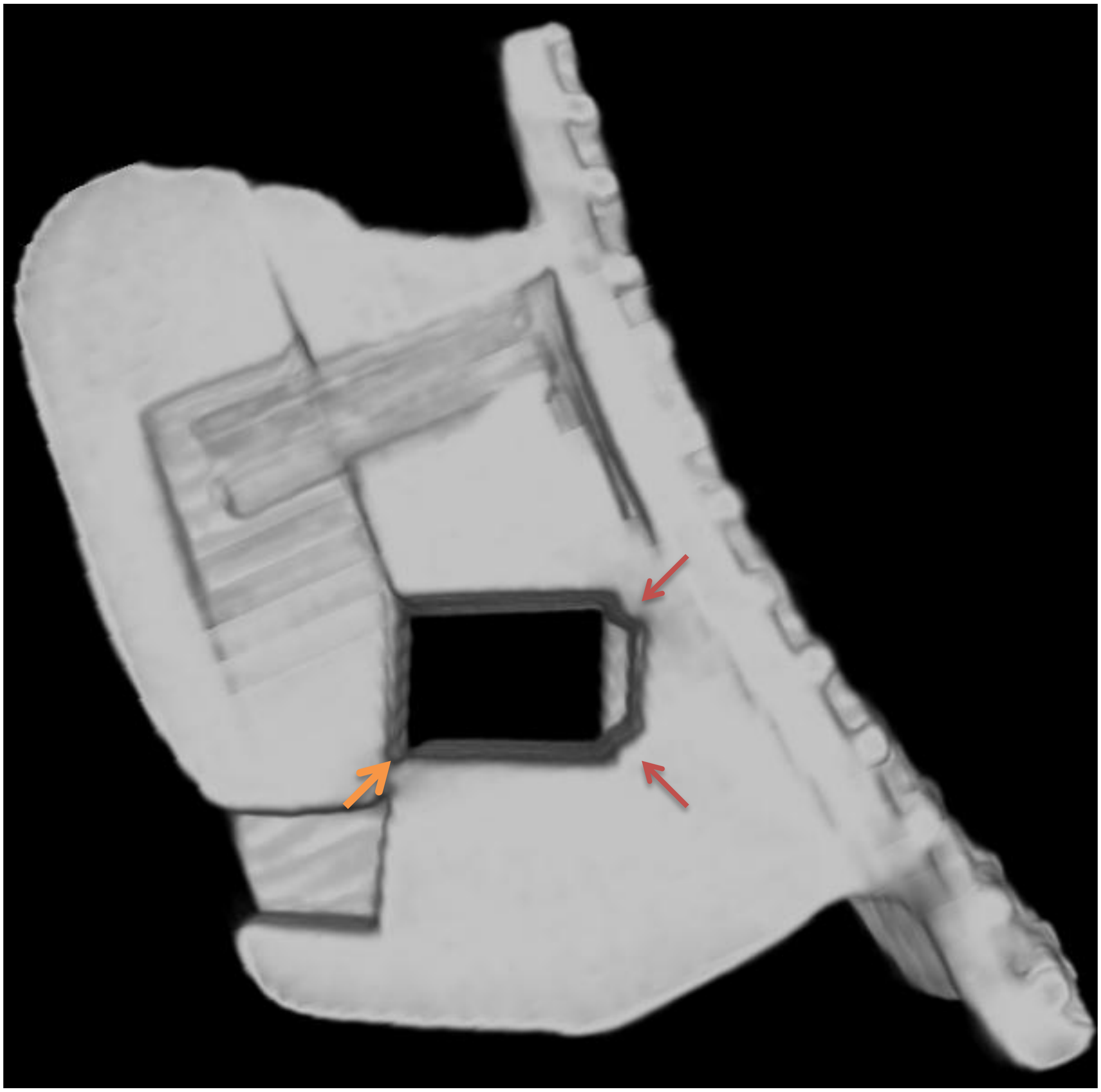


Figure 10: Sample #4 illustrates notched (←) and irregular, beveled (➔) corners.

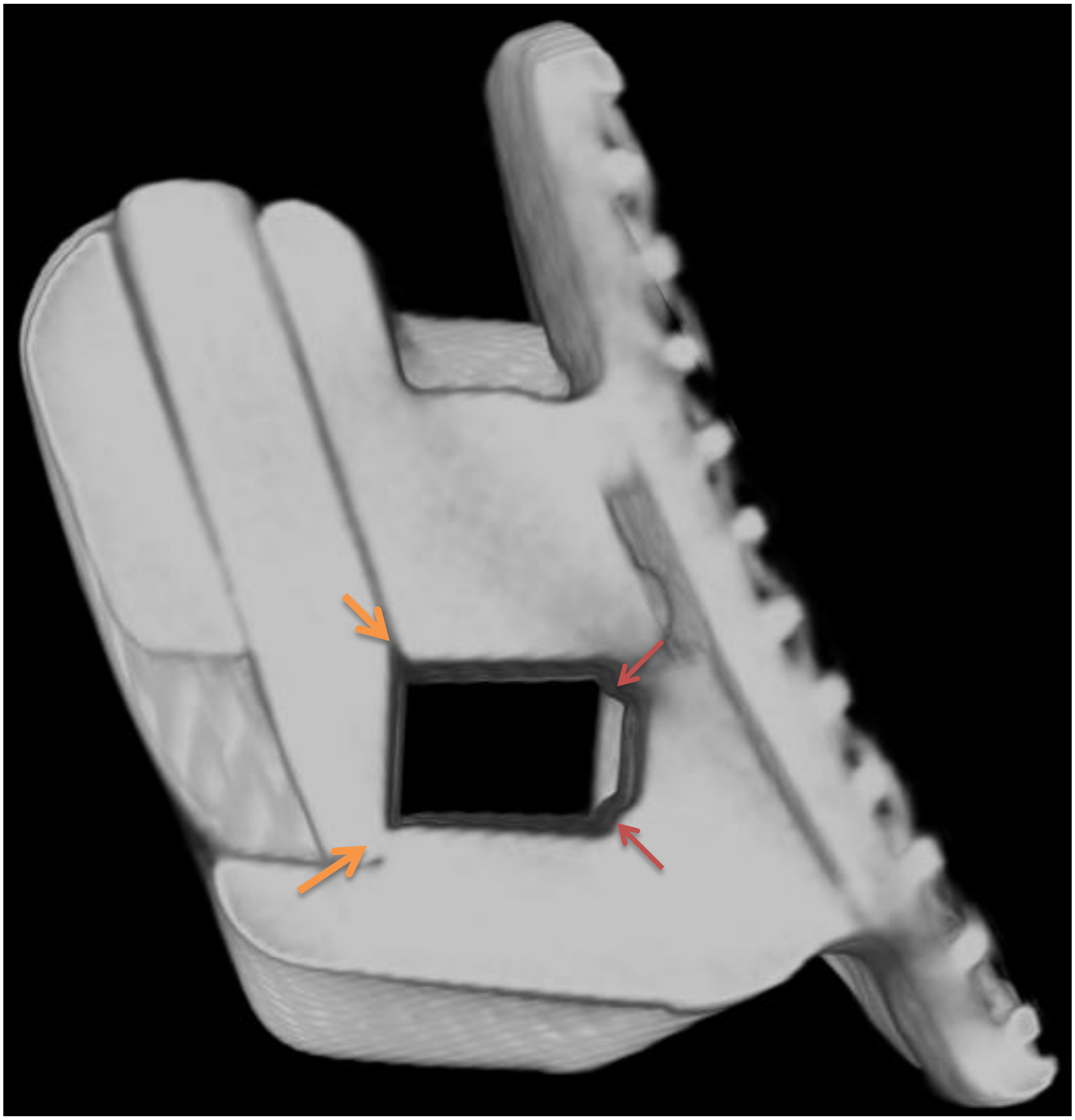


Figure 11: Sample #5 illustrates notched (←) and irregular, beveled (➔) corners.

5.3.2 American Orthodontics – Empower System

MicroCT Images of Defects

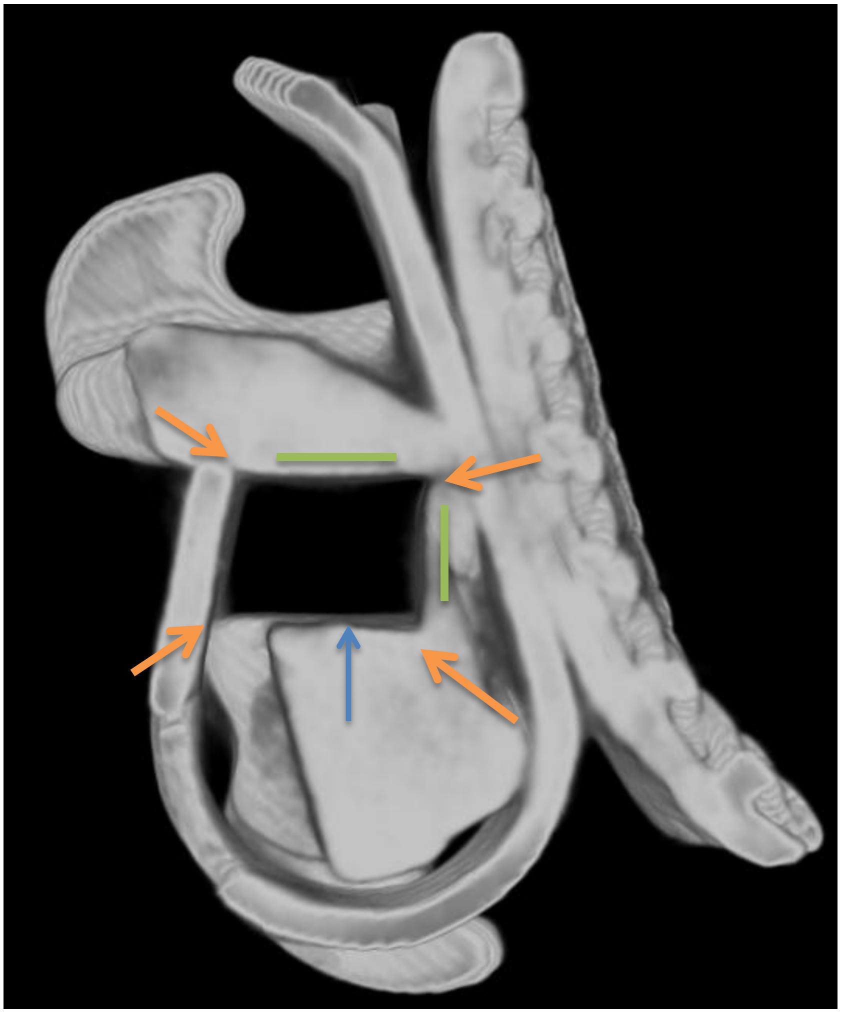


Figure 12: Sample #1 illustrates irregular, beveled (→) corners and contains a bulbous metal projection (←) along the bottom horizontal wall. In addition this sample displays highly irregular and bulbous shaped walls ( )rather than straight and rectangular.

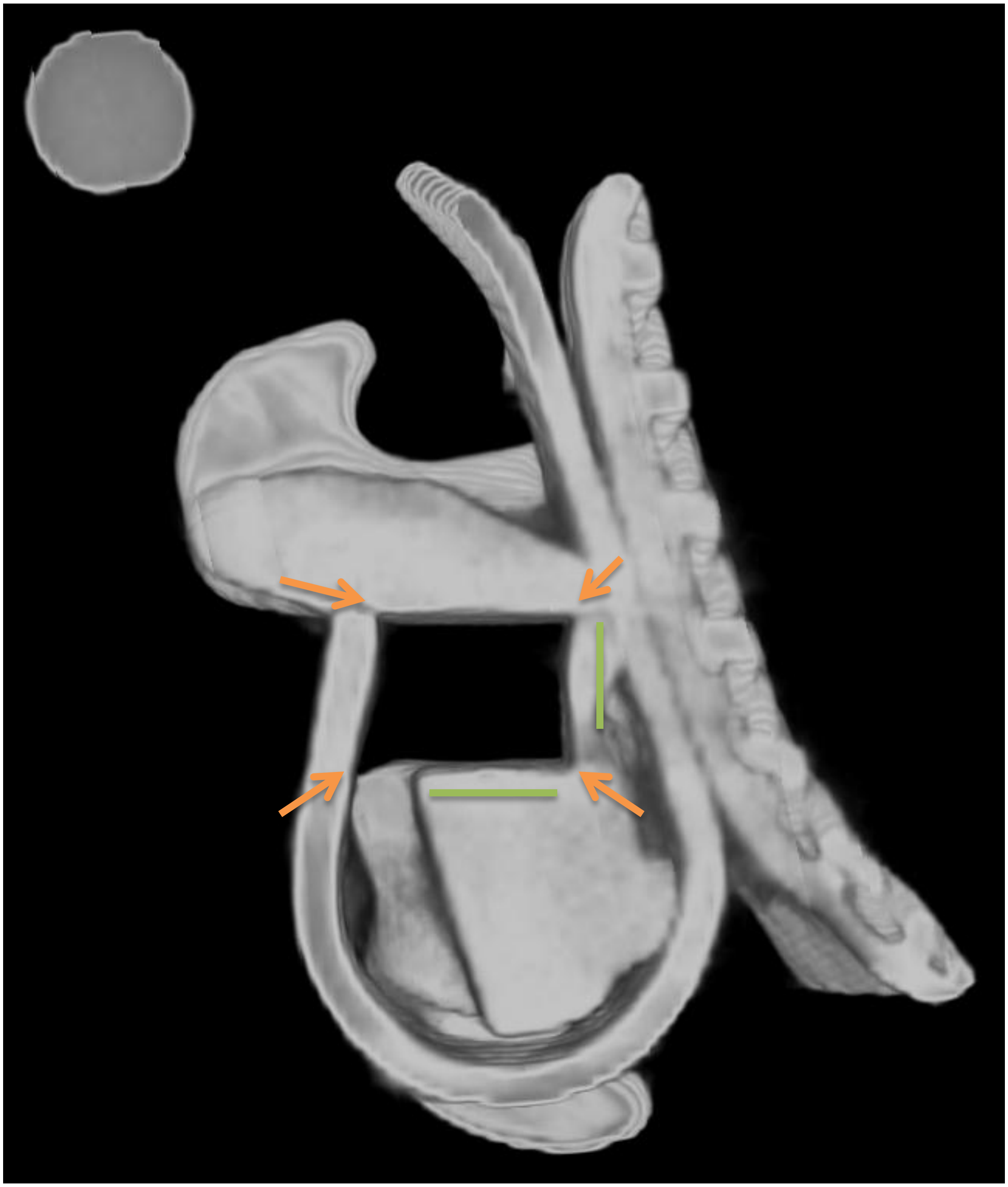


Figure 13: Sample #2 illustrates irregular, beveled ( ) corners. In addition this sample displays highly irregular and bulbous shaped walls ( ) rather than straight and rectangular.

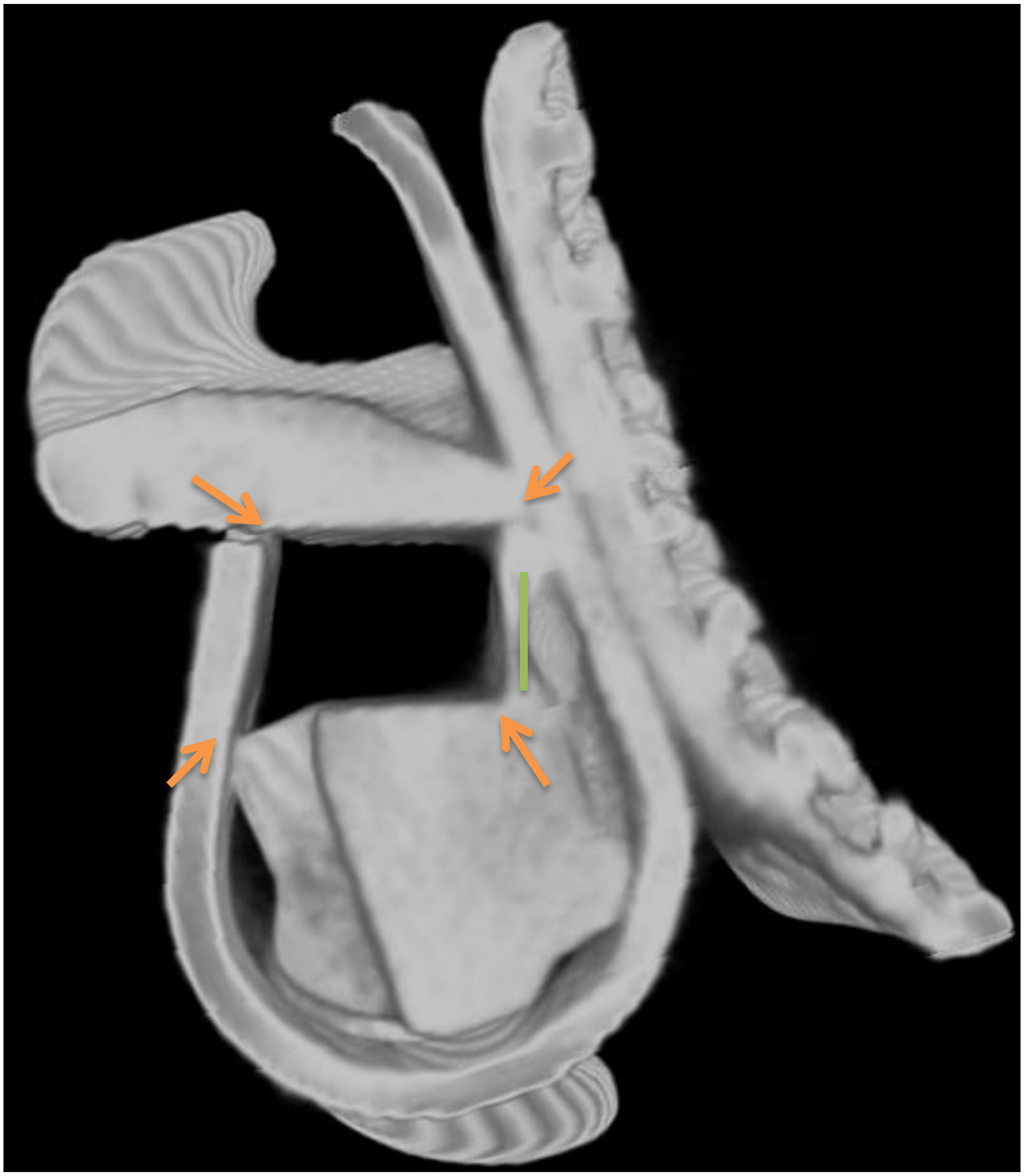


Figure 14: Sample #3 illustrates irregular, beveled ( ) corners. In addition this sample displays highly irregular and bulbous shaped walls ( ) rather than straight and rectangular.

Figure 15: Sample #4 illustrates irregular, beveled (→) corners. In addition this sample displays highly irregular and bulbous shaped walls (—) rather than straight and rectangular.

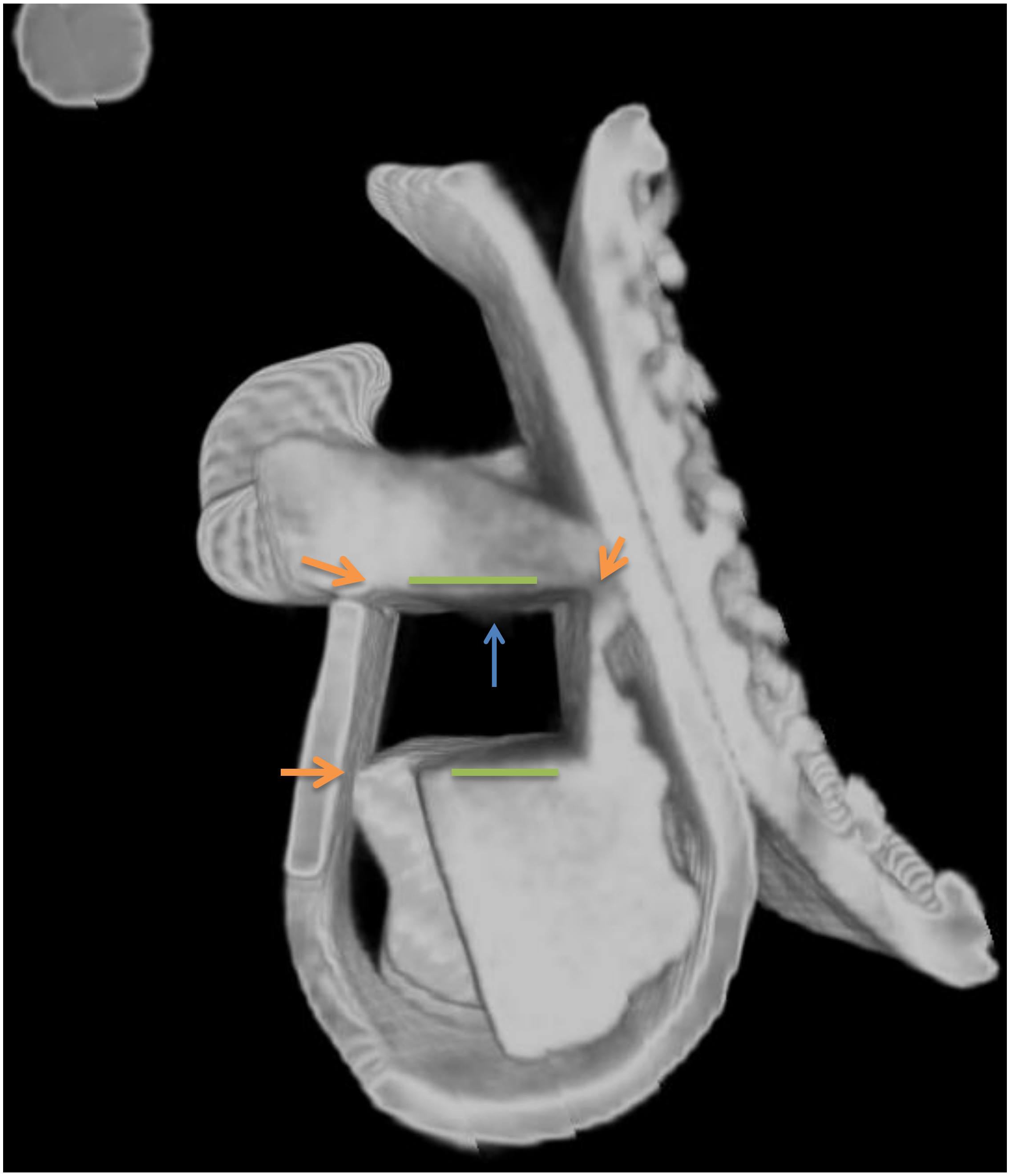


Figure 16: Sample #5 illustrates irregular, beveled (→) corners and contains a bulbous metal projection (←) along the top horizontal wall. In addition this sample displays highly irregular and bulbous shaped walls (▬) rather than straight and rectangular.

5.3.3 GAC - InOvation System

MicroCT Images of Defects

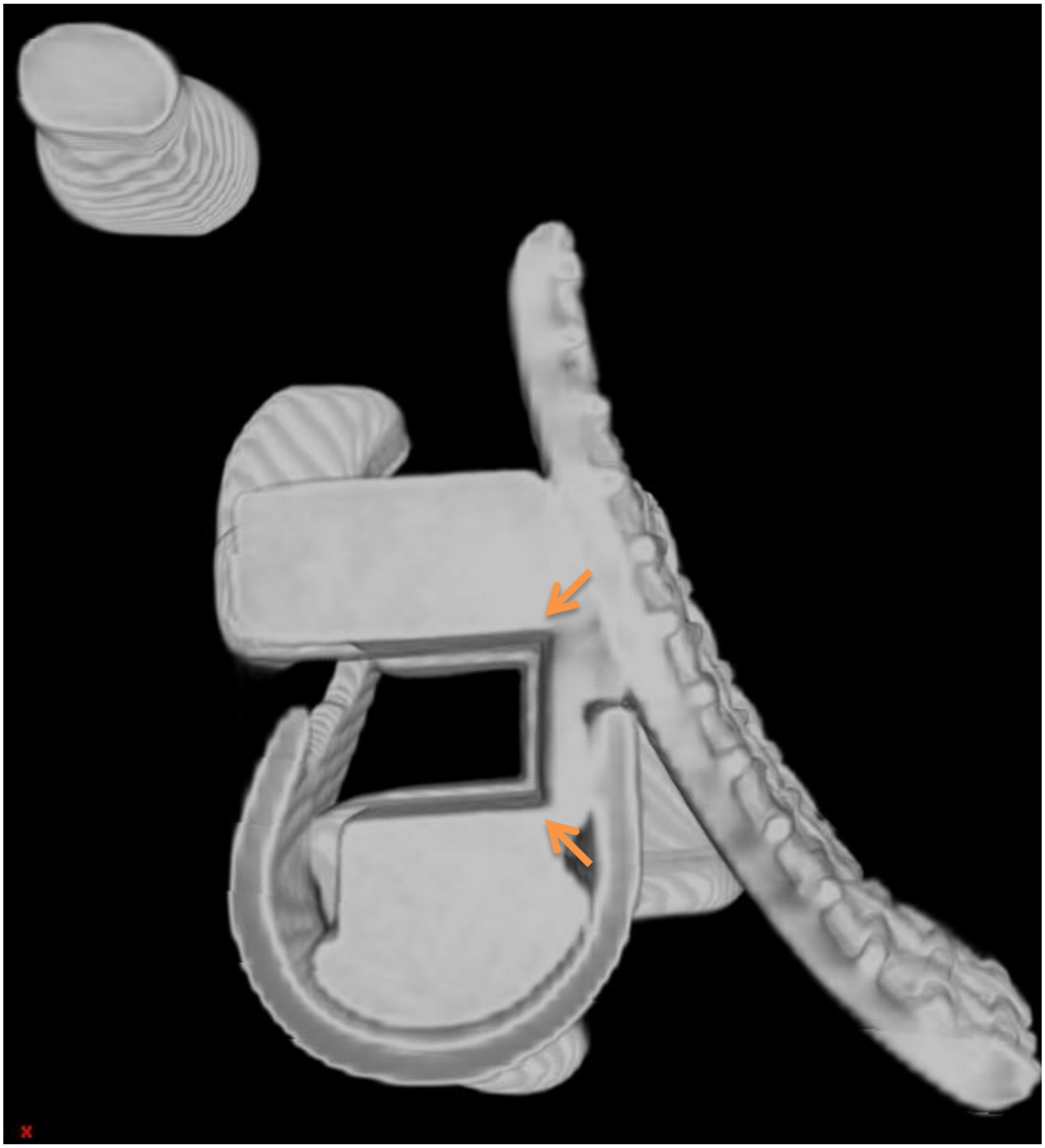


Figure 17: Sample #1 illustrates irregular, beveled (→) corners.

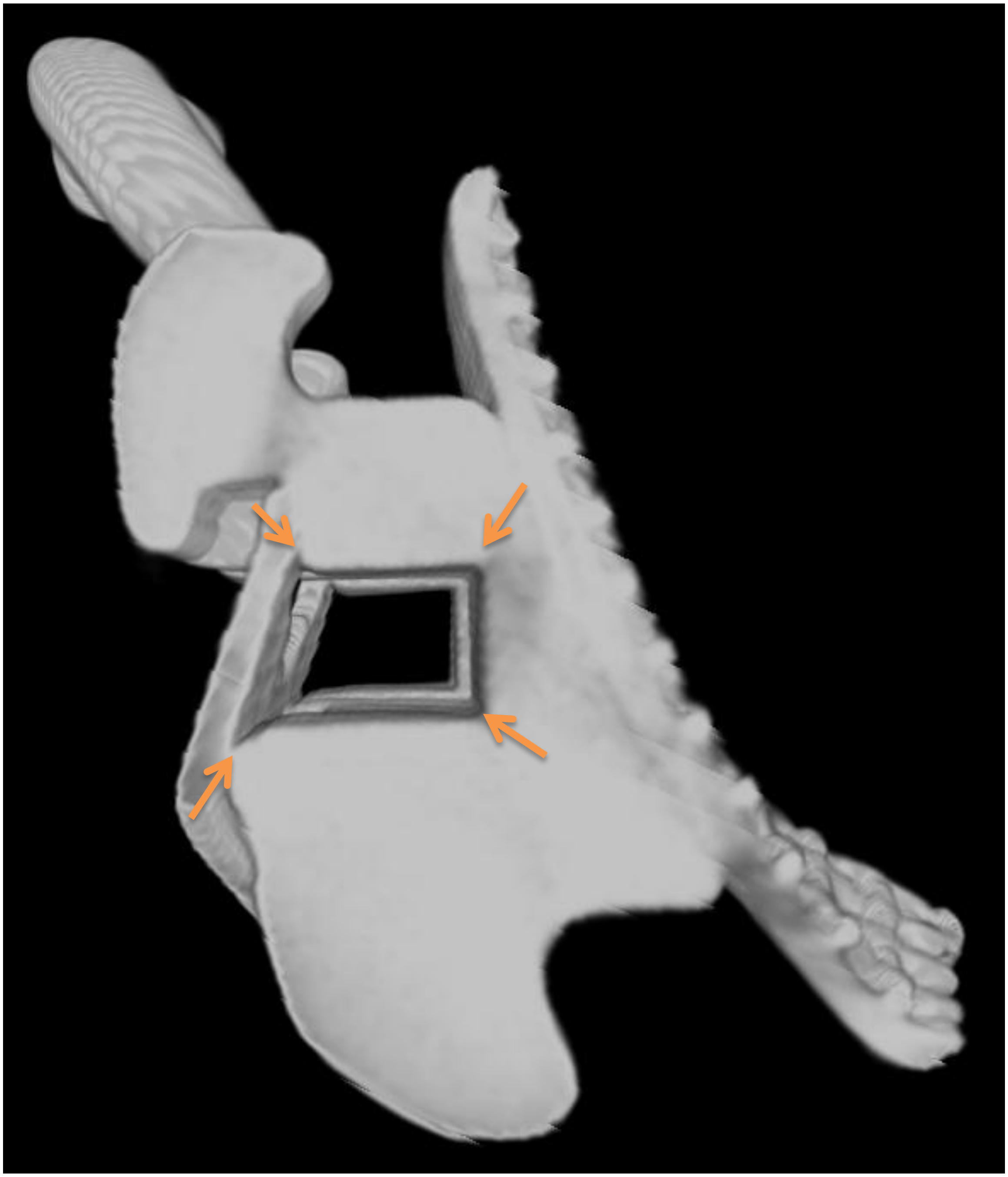


Figure 18: Sample #2 illustrates irregular, beveled (→) corners.

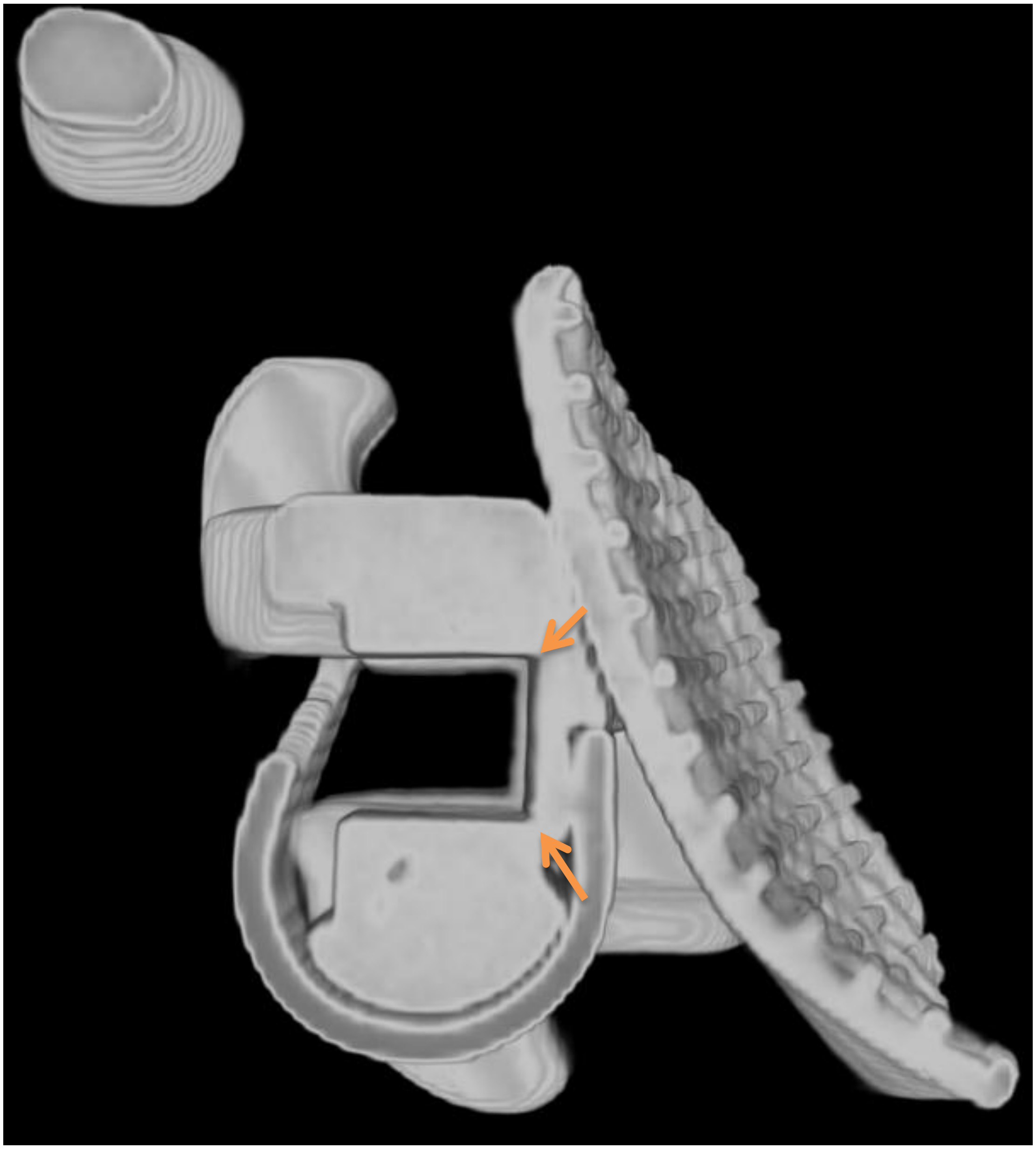


Figure 19: Sample #3 illustrates irregular, beveled (→) corners.

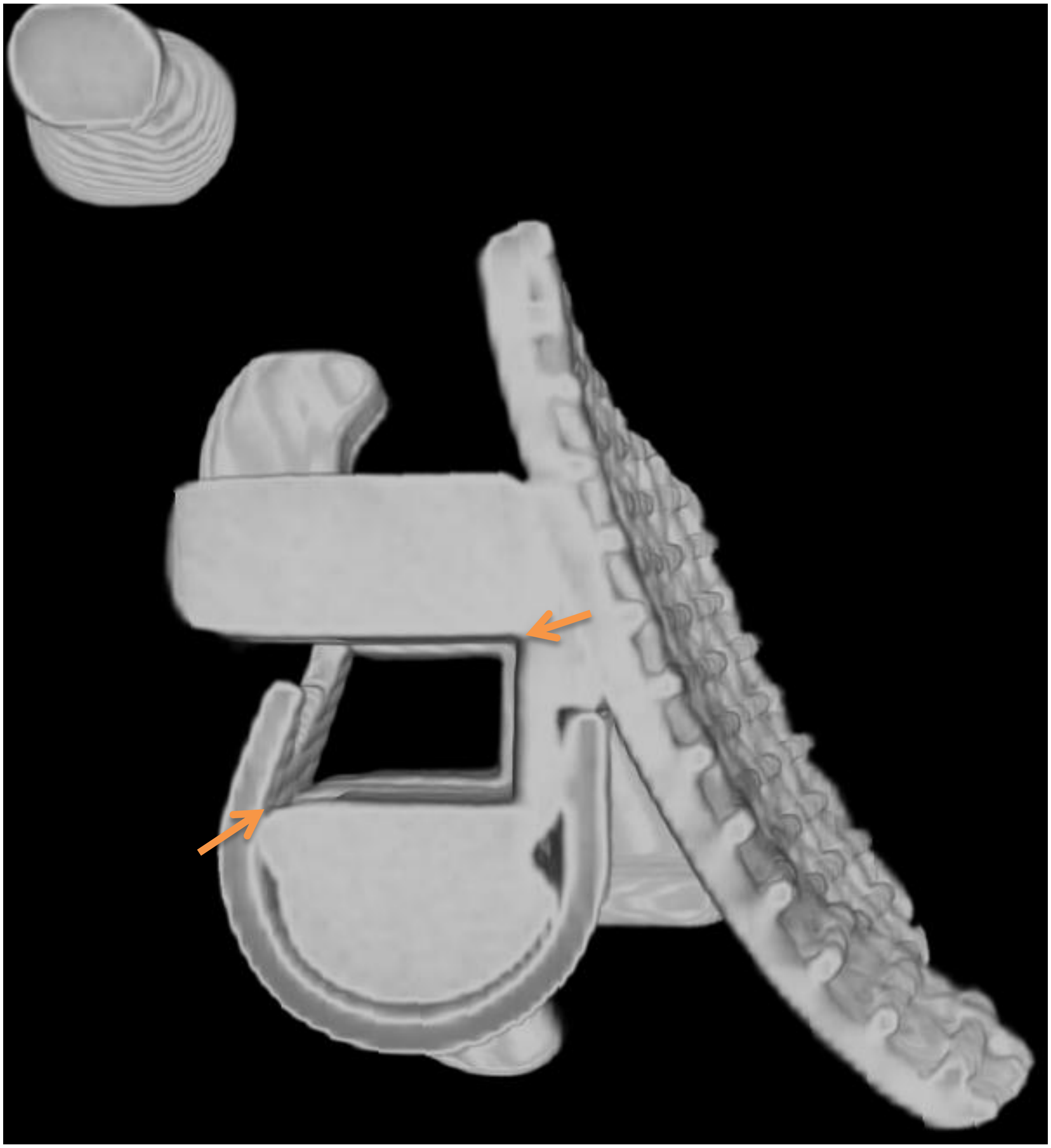


Figure 20: Sample #4 illustrates irregular, beveled (→) corners.

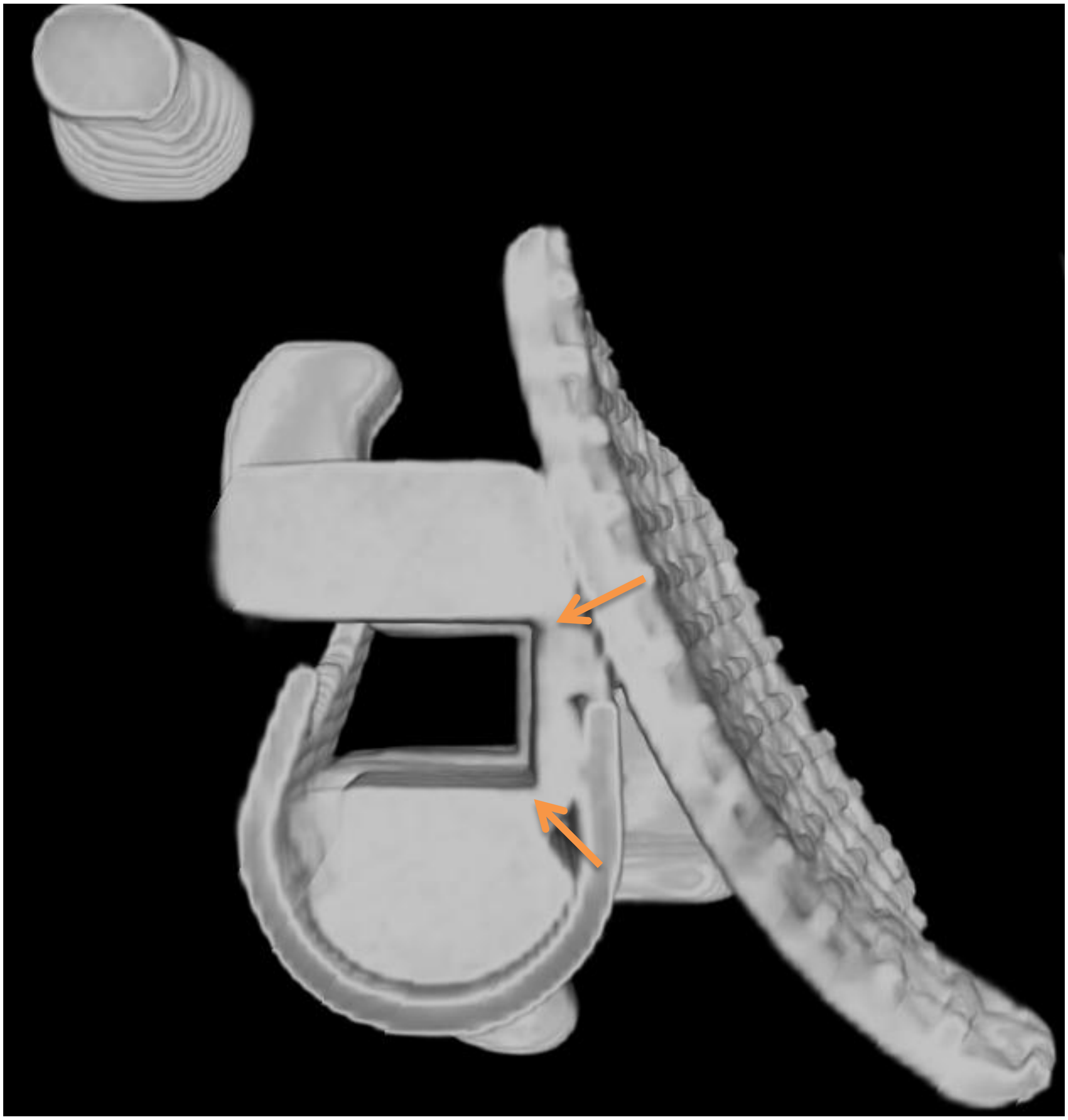


Figure 21: Sample #5 illustrates irregular, beveled (→) corners.

5.3.4 Forestadent – BioQuick System

MicroCT Images of Defects

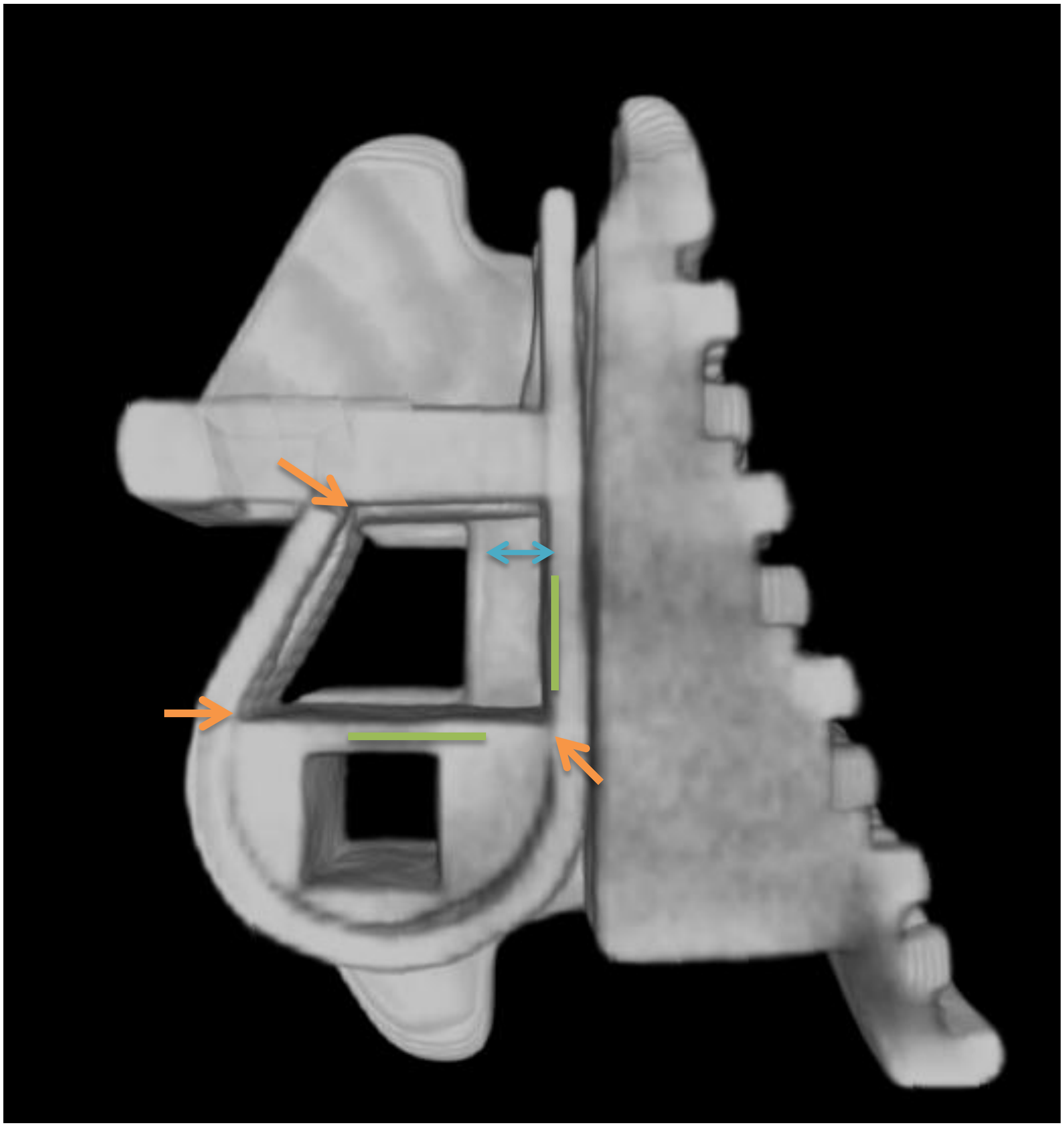


Figure 22: Sample #1 illustrates irregular, beveled (→) corners and irregular and bulbous shaped walls (—). In addition this sample portrays several millimeters of internal slot length that are excessive (↔)in overall size and would yield no significant engagement of a selected rectangular arch wire. The only portions capable of engagement are found at the most mesial and distal aspects of the slot lumen.

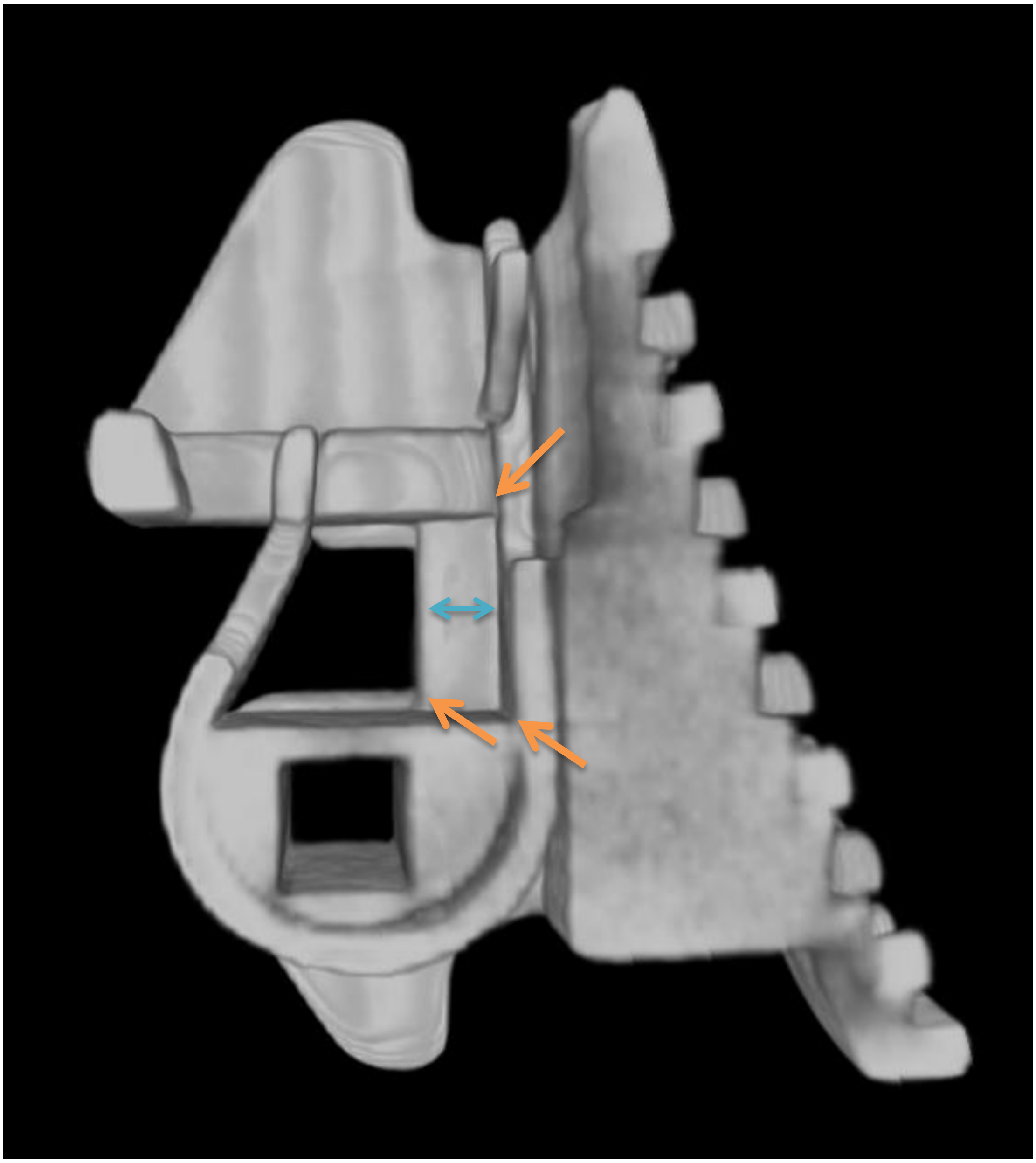


Figure 23: Sample #2 illustrates irregular, beveled (→) corners. In addition this sample portrays several millimeters of internal slot length that are excessive (↔)in overall size and would yield no significant engagement of a selected rectangular arch wire. The only portions capable of engagement are found at the most mesial and distal aspects of the slot lumen.

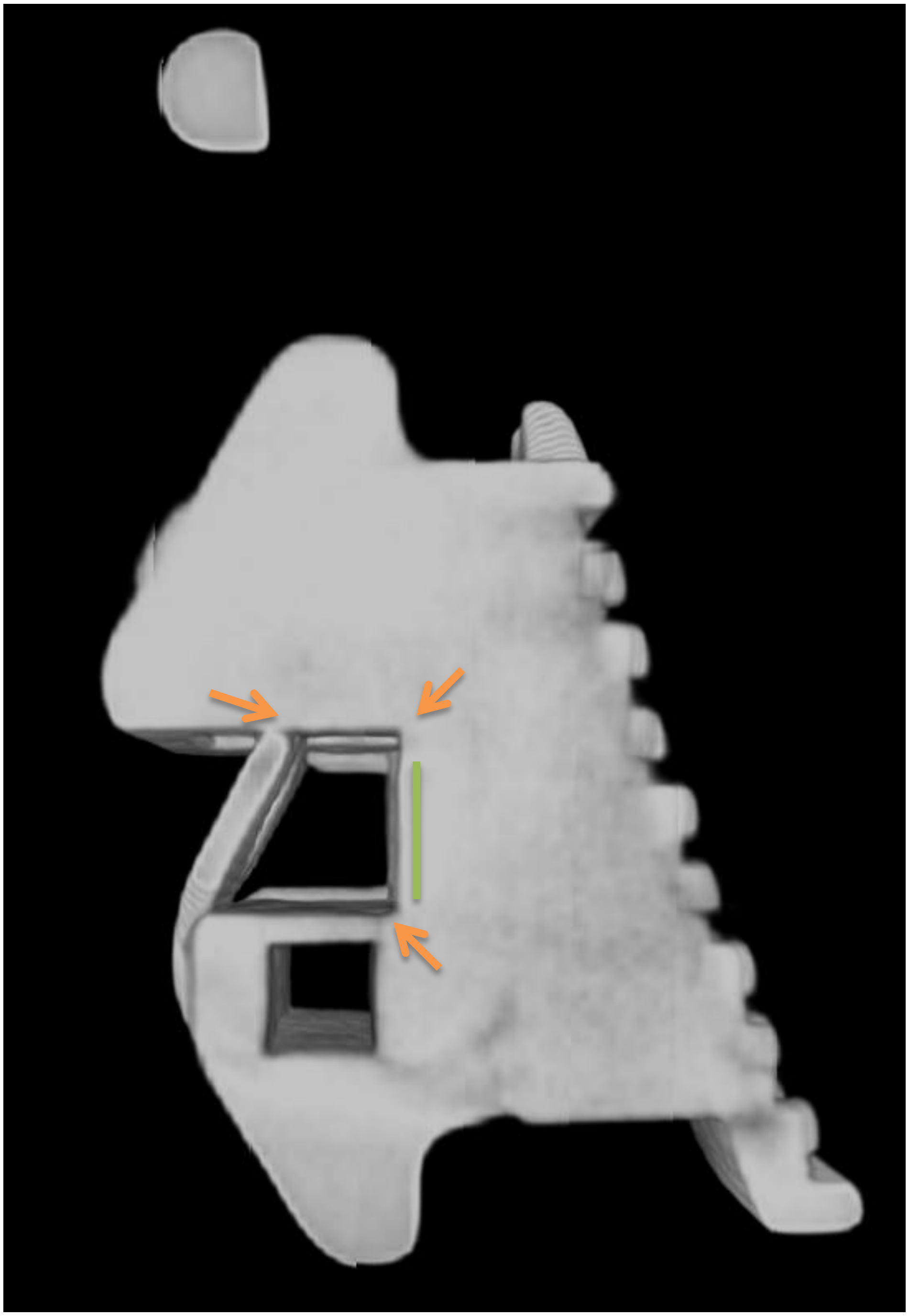


Figure 24: Sample #3 illustrates irregular, beveled (→) corners and irregular and bulbous shaped walls (▬).

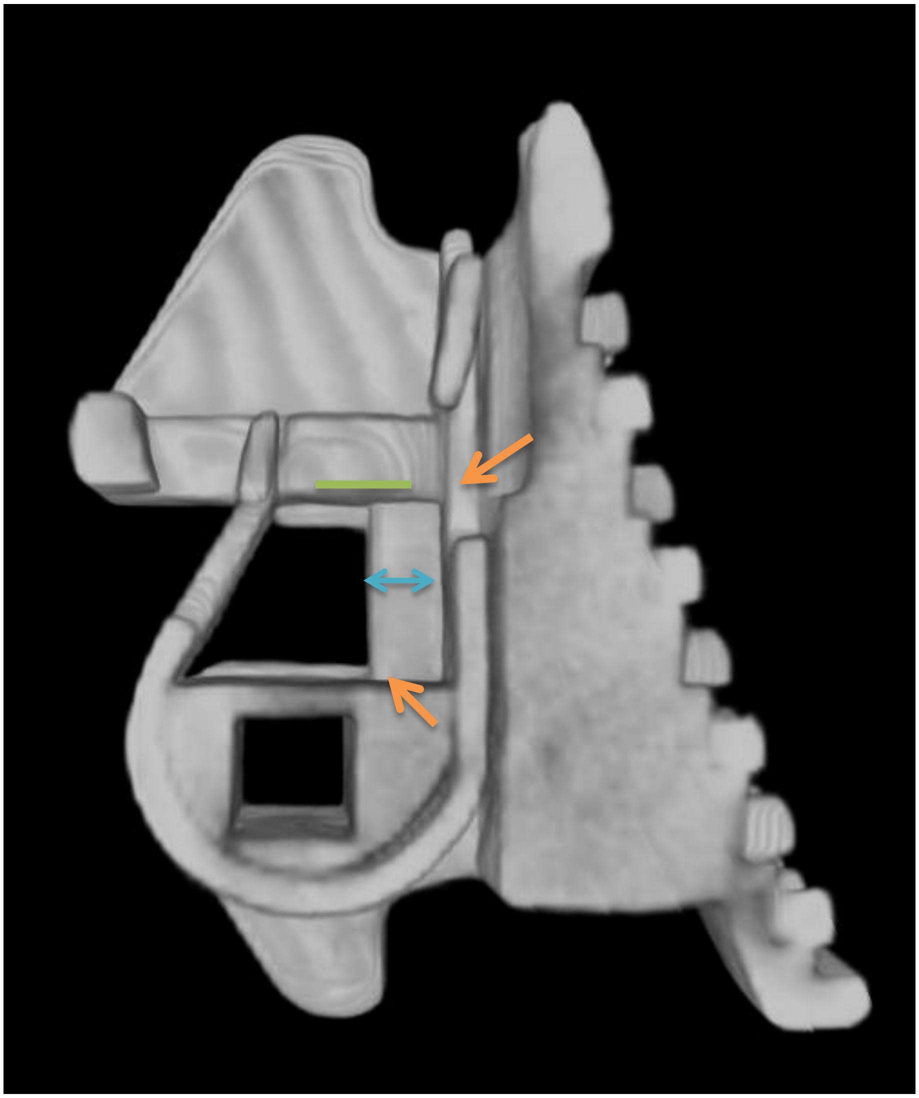


Figure 25: Sample #4 illustrates irregular, beveled (→) corners and irregular and bulbous shaped walls (▬). In addition this sample portrays several millimeters of internal slot length that are excessive (↔)in overall size and would yield no significant engagement of a selected rectangular arch wire. The only portions capable of engagement are found at the most mesial and distal aspects of the slot lumen.

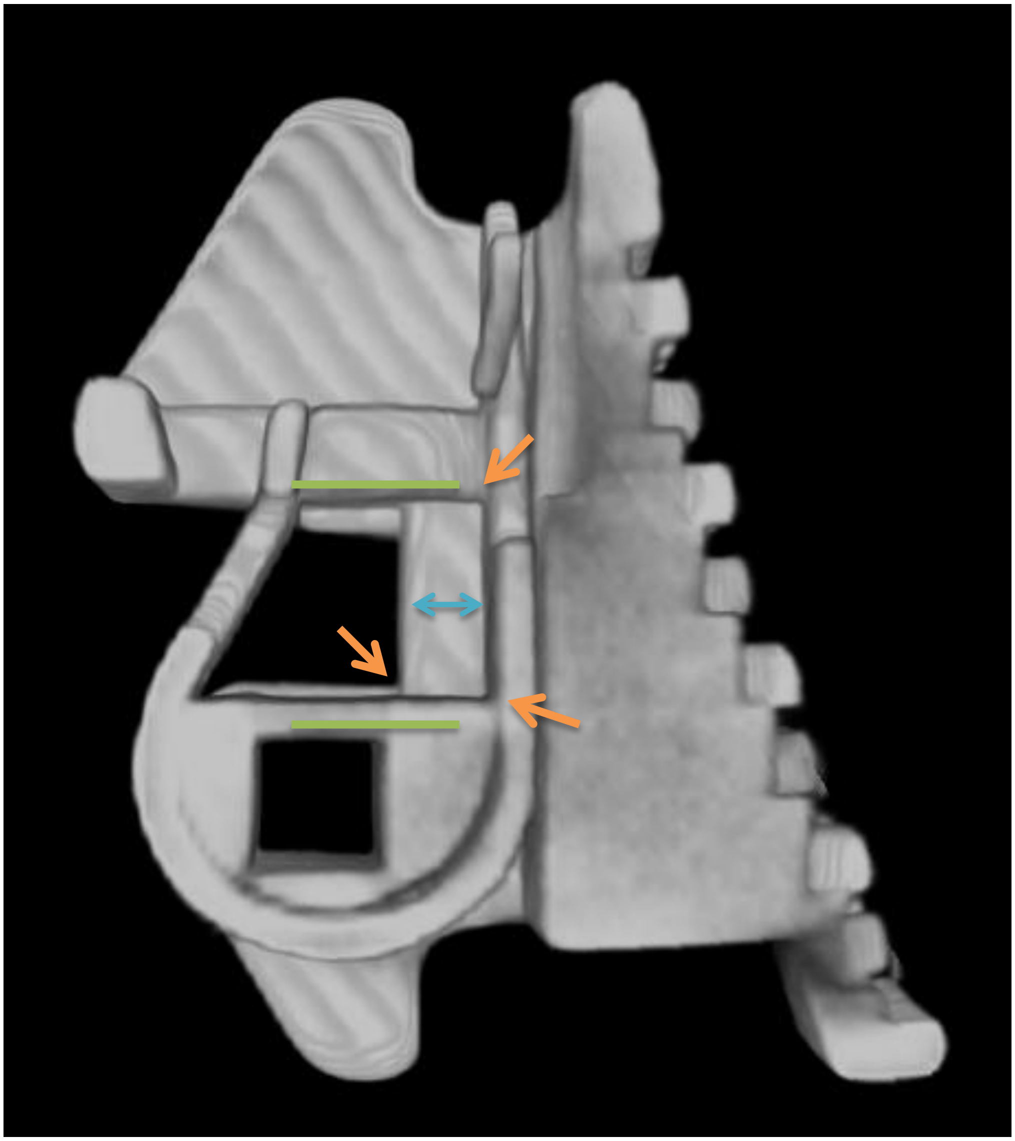


Figure 26: Sample #5 illustrates irregular, beveled (→) corners and irregular and bulbous shaped walls (—). In addition this sample portrays several millimeters of internal slot length that are excessive (↔)in overall size and would yield no significant engagement of a selected rectangular arch wire. The only portions capable of engagement are found at the most mesial and distal aspects of the slot lumen.

CHAPTER 6

DISCUSSION

Measurements done by micro-CT in this investigation show that all self-ligating tubes from four different manufacturers had over-sized slot lumens as compared with the ADA prescribed standard. The potential clinical significance of inaccurate slot dimensions may compromise the three dimensional control required by orthodontists to produce an intended treatment result. Furthermore, this lack of torque control may require the practitioner to make various bends in the arch wire to counteract these potential side effects. Although no studies to date have investigated the potential side effects of oversized molar tubes on the position of posterior teeth within the dental arches, Siatkowski[27] illustrated the effects of oversized brackets on anterior torque loss during space closure. He noted that maxillary and mandibular incisors may suffer a loss of 5-10 degrees of torque, which equates to 1.9mm of lingual retrusion of incisal edges when protracting the buccal segments during space closure with the pre-adjusted Edgewise appliance.[27,31]

Qualitative analysis of the samples tested illustrated varying defects contained within their respective internal slot lumens. These defects and imperfections ranged in their consistency and severity including notched, beveled, and irregular corners, as well as the presence of some bulbous metal projections. The potential clinical significance of these internal surface imperfections may produce an increased amount of friction during tooth movements. Although previous in-vitro studies[15,17-22] have illustrated that less friction is generated with self-ligating brackets versus conventional brackets, the potential effects of additional friction on desired tooth movements have not been fully addressed in the clinical setting.

6.1 Limitations and Future direction

This study aimed to develop a novel approach for analysis and methodology in measuring the accuracy and quality of orthodontic brackets and molar buccal tubes. Utilizing Micro-computed Tomography (MicroCT), we investigated reconstructed cross sectional slices of self-ligating molar tubes manufactured by four different companies. The development of this technology allowed the investigator to obtain high resolution, three-dimensional structural information that previously was not available by standard two-dimensional analysis. However, developing a new method for qualitative and quantitative analysis may result in confounding variables not addressed using previous methods. For example, the acceptable parameters of a .022 bracket slot is 0.0225 x 0.0285 inches, which is a two dimensional measurement. In order to accurately represent the three-dimensional internal slot measurements of our samples, we had to convert these parameters into volumetric measurements by multiplying the total internal slot length investigated. Therefore, these measurements varied based on the overall length of each individual sample, which may have confounded the statistical results illustrated by the differences between standard deviation and variance (Table 1). If “slot volume” is not selected to determine the dimensional accuracy in future studies, perhaps one could develop a methodology in which the measurements could be taken at consistent and different locations within each samples’ slot: 1) mesial slot entrance, 2) ¼ distance (internal slice), 3) ½ distance (internal slice), 4) ¾ distance (internal slice), and 5) distal slot exit.

We selected self-ligating tubes with a .022 slot. Future studies should include conventional molar tubes, self-ligating brackets, and examine these appliances with the smaller dimension .018 slot. In addition, future directions of study could include examining the angle formed between the slot and the base, which determines the torque applied to an individual tooth.

Finally, this study only examined the dimensional accuracy and integrity of these slot lumens prior to their use. Future studies should be performed to evaluate the precision, quality, and stability of bracket and tube slots over a period of time to represent any changes that can occur following the repeated insertion and removal of arch wires throughout treatment.

CHAPTER 7

CONCLUSIONS

- This study provides a novel approach for analysis and methodology for measuring the accuracy and quality of orthodontic brackets and molar buccal tubes.
- Micro-computed Tomography (micro-CT) provides 3D structural information that can be used for future studies examining orthodontic materials.
- All the self-ligating molar tubes evaluated in this study had oversized slot lumens that contained various defects and imperfections, which may result in an increased amount of friction as well as loss of torque control during orthodontic treatment.
- Future studies should utilize micro-CT and include examining self-ligating brackets, conventional brackets and molar tubes, brackets and molar tubes with 018 slots, and compare the dimensional accuracy and stability of these materials prior to their use versus the changes observed over time following repeated insertion and removal of arch wires.

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APPENDICES

APPENDIX A

	Sample #	Number of slices	Upper vertical limit	Lower vertical limit	Total internal slot length (inches) = *Upper vertical limit - Lower vertical limit*	Control acceptable parameters *(0.0225x0.0285 inches)*	Adjusted volumetric parameters for control (cubic inches) = *"control acceptable parameters" x total internal slot length*
Damon	1	596	2.0088E-01	6.3180E-02	1.3770E-01	6.4125E-04	8.8300E-05
Damon	2	596	1.9695E-01	5.9246E-02	1.3770E-01	6.4125E-04	8.8299E-05
Damon	3	596	2.0921E-01	7.1511E-02	1.3770E-01	6.4125E-04	8.8300E-05
Damon	4	596	1.6547E-01	2.7771E-02	1.3770E-01	6.4125E-04	8.8300E-05
Damon	5	596	1.9764E-01	5.9940E-02	1.3770E-01	6.4125E-04	8.8300E-05
Empower	1	489	1.5043E-01	3.7491E-02	1.1294E-01	6.4125E-04	7.2421E-05
Empower	2	489	1.5899E-01	4.6054E-02	1.1294E-01	6.4125E-04	7.2421E-05
Empower	3	466	1.5830E-01	5.0683E-02	1.0761E-01	6.4125E-04	6.9007E-05
Empower	4	457	1.6570E-01	6.0171E-02	1.0553E-01	6.4125E-04	6.7672E-05
Empower	5	478	1.4511E-01	3.4714E-02	1.1039E-01	6.4125E-04	7.0788E-05
InOvation	1	501	1.8977E-01	7.4057E-02	1.1571E-01	6.4125E-04	7.4202E-05
InOvation	2	501	1.9301E-01	7.7297E-02	1.1571E-01	6.4125E-04	7.4202E-05
InOvation	3	501	1.9903E-01	8.3314E-02	1.1571E-01	6.4125E-04	7.4202E-05
InOvation	4	501	1.9093E-01	7.5214E-02	1.1571E-01	6.4125E-04	7.4202E-05
InOvation	5	461	1.9903E-01	9.2571E-02	1.0646E-01	6.4125E-04	6.8266E-05
BioQuick	1	301	1.6223E-01	9.2803E-02	6.9428E-02	6.4125E-04	4.4521E-05
BioQuick	2	301	1.2729E-01	5.7857E-02	6.9428E-02	6.4125E-04	4.4521E-05
BioQuick	3	301	1.6200E-01	9.2571E-02	6.9429E-02	6.4125E-04	4.4521E-05
BioQuick	4	301	1.7126E-01	1.0183E-01	6.9429E-02	6.4125E-04	4.4521E-05
BioQuick	5	301	1.0183E-01	3.2400E-02	6.9428E-02	6.4125E-04	4.4521E-05

Appendix A (above): Samples analyzed for dimensional accuracy. The acceptable parameters used as the control for dimensional accuracy analysis, were converted into volumetric dimensions by multiplying the 0.0225 x 0.0285 inches times each individual samples' total internal lumen length (in inches) analyzed. "Adjusted volumetric parameters" were used as the control for comparison of the individual samples' respective "slot volume" analyzed.

APPENDIX B

	Sample #	Total Volume *(TV)*	Object Volume *(OV)*	Slot Volume *(TV - OV)*	**Adjusted volumetric parameters for control** (cubic inches) = "control acceptable parameters" x total internal slot length	**DIFFERENCE** = Slot Volume - adjusted volumetric parameters for control
Damon	1	1.3000E-04	2.0000E-05	1.1000E-04	8.8300E-05	**2.1700E-05**
Damon	2	1.3000E-04	2.0000E-05	1.1000E-04	8.8299E-05	**2.1701E-05**
Damon	3	1.2000E-04	2.0000E-05	1.0000E-04	8.8300E-05	**1.1700E-05**
Damon	4	1.3000E-04	2.0000E-05	1.1000E-04	8.8300E-05	**2.1700E-05**
Damon	5	1.3000E-04	2.0000E-05	1.1000E-04	8.8300E-05	**2.1700E-05**
Empower	1	1.3000E-04	2.0000E-05	1.1000E-04	7.2421E-05	**3.7579E-05**
Empower	2	1.1000E-04	2.0000E-05	9.0000E-05	7.2421E-05	**1.7579E-05**
Empower	3	1.0000E-04	2.0000E-05	8.0000E-05	6.9007E-05	**1.0993E-05**
Empower	4	9.0000E-05	1.0000E-05	8.0000E-05	6.7672E-05	**1.2328E-05**
Empower	5	1.1000E-04	1.0000E-05	1.0000E-04	7.0788E-05	**2.9212E-05**
InOvation	1	1.5000E-04	2.0000E-05	1.3000E-04	7.4202E-05	**5.5798E-05**
InOvation	2	1.5000E-04	2.0000E-05	1.3000E-04	7.4202E-05	**5.5798E-05**
InOvation	3	1.5000E-04	2.0000E-05	1.3000E-04	7.4202E-05	**5.5798E-05**
InOvation	4	1.5000E-04	2.0000E-05	1.3000E-04	7.4202E-05	**5.5798E-05**
InOvation	5	1.5000E-04	2.0000E-05	1.3000E-04	6.8266E-05	**6.1734E-05**
BioQuick	1	1.1000E-04	2.0000E-05	9.0000E-05	4.4521E-05	**4.5479E-05**
BioQuick	2	1.0000E-04	2.0000E-05	8.0000E-05	4.4521E-05	**3.5479E-05**
BioQuick	3	1.4000E-04	2.0000E-05	1.2000E-04	4.4521E-05	**7.5479E-05**
BioQuick	4	1.2000E-04	1.0000E-05	1.1000E-04	4.4521E-05	**6.5479E-05**
BioQuick	5	1.1000E-04	2.0000E-05	9.0000E-05	4.4521E-05	**4.5479E-05**

Appendix B (above). Samples analyzed for dimensional accuracy. All values are in inches. The difference represents the slot volume (total volume minus object volume) minus the adjusted volumetric parameters used as control.

APPENDIX C

Descriptive statistics results

DAMON	
Mean	1.97E-05
Standard Error	2.00E-06
Median	2.17E-05
Mode	2.17E-05
Standard Deviation	4.47E-06
Sample Variance	2.00E-11
Kurtosis	5.00E+00
Skewness	-2.24E+00
Range	1.00E-05
Minimum	1.17E-05
Maximum	2.17E-05
Sum	9.85E-05
Count	5
Largest(1)	2.17E-05
Smallest(1)	1.17E-05
Confidence Level(95.0%)	5.55E-06

Empower	
Mean	2.15E-05
Standard Error	5.14E-06
Median	1.76E-05
Mode	#N/A
Standard Deviation	1.15E-05
Sample Variance	1.32E-10
Kurtosis	-1.58E+00
Skewness	7.04E-01
Range	2.66E-05
Minimum	1.10E-05
Maximum	3.76E-05
Sum	1.08E-04
Count	5
Largest(1)	3.76E-05
Smallest(1)	1.10E-05
Confidence Level(95.0%)	1.43E-05

InOvation	
Mean	5.70E-05
Standard Error	1.19E-06
Median	5.58E-05
Mode	5.58E-05
Standard Deviation	2.65E-06
Sample Variance	7.05E-12
Kurtosis	5.00E+00
Skewness	2.24E+00
Range	5.94E-06
Minimum	5.58E-05
Maximum	6.17E-05
Sum	2.85E-04
Count	5
Largest(1)	6.17E-05
Smallest(1)	5.58E-05
Confidence Level(95.0%)	3.30E-06

BioQuick	
Mean	5.35E-05
Standard Error	7.35E-06
Median	4.55E-05
Mode	#N/A
Standard Deviation	1.64E-05
Sample Variance	2.70E-10
Kurtosis	-1.69E+00
Skewness	5.18E-01
Range	4.00E-05
Minimum	3.55E-05
Maximum	7.55E-05
Sum	2.67E-04
Count	5
Largest(1)	7.55E-05
Smallest(1)	3.55E-05
Confidence Level(95.0%)	2.04E-05