# ORTHODONTIC TOOTH MOVEMENT (OTM) WITH CLEAR ALIGNERS

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
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To my wife and children for bringing me peace and happiness

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Thesis Presented to the Graduate School
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The following observations regarding tooth movement with Invisalign aligners resulted from a randomized and controlled clinical trial performed at the University of Florida (UF) in 2005: 1) more orthodontic tooth movement (OTM) occurred during the first week versus the second week of aligner wear for each two-week prescription cycle, 2) the full prescription of the aligners were not expressed, and 3) OTM was highly variable among individuals. These observations have clinical implications and require further research.

The primary aim of this study was to determine whether these observations were due to material fatigue of the aligners in the oral environment. The secondary aim of this study was to describe and quantify the type and amount of OTM produced by clear aligners.

A prospective single center clinical trial was completed, comparing 15 subjects treated over a course of eight weeks with a control group of 37 subjects from the UF study with similar population demographics and nearly identical study design. An upper central incisor was programmed to move two mm over eight weeks, or 0.5 mm every two weeks, using Invisalign® aligners. The treatment subjects changed to a fresh

aligner with the same prescription after one week, and the control subjects wore each aligner for the prescribed two weeks. Weekly polyvinyl siloxane (PVS) impressions were taken and digital models were fabricated to measure OTM. In addition, initial and final cone beam computed tomography (CBCT) images were obtained from the treatment subjects only, to describe and measure OTM.

No significant difference was found in the amount of OTM between those who wore the same aligner for two weeks vs. those who changed to a fresh aligner after one week. Therefore, the reduction in the amount of OTM seen during the second week of aligner wear was unlikely to be due to material fatigue. There was, however, a significant difference in OTM during the first week vs. the second week of any given two-week cycle, for both groups.

When OTM was measured from the centroid of the clinical crown, the two mm prescription of the aligners was not fully expressed in any of the 15 treated subjects. High variability was observed. In addition, CBCT data indicated that: 1) the target teeth experienced uncontrolled tipping, with the median center of rotation located 41% of the root length apical to the alveolar crest, 2) although only one central incisor was programmed to move, the contralateral central incisor felt a reactive force and moved in the opposite direction of the target tooth, 3) seven of the 15 subjects experienced a net anteroposterior (A-P) change of less than 1.9 mm between the midpoint of the incisal edge of the target tooth and the contralateral central incisor, and 4) the results of an exploratory data analysis attempting to correlate biologic variables with OTM revealed some trends, but additional research is required before making conclusions.

# CHAPTER 1
# INTRODUCTION

Research involving the Invisalign® system is lacking. Most of the available literature consists of case reports, editorials, or articles written by authors with bias. There have been no evidence-based attempts to describe the type of OTM resulting from treatment with clear aligners. Conventional thinking suggests that the movement is mostly uncontrolled tipping, with the center of rotation located between the center of resistance and the apex of the tooth. The center of resistance of a single-rooted tooth has been reported to be on the long axis of the tooth between one third and one half of the root length apical to the alveolar crest.[1]

Duong et al.[2] compared the load-deflection rates (LDR) of 0.017x0.017'' stainless steel (SS) and Nickel Titanium (NiTi) wires vs. 0.030 mm polyurethane material over a 0-10% range of strain in vitro. The LDR of the polyurethane was greater than the NiTi wire but less than the stainless steel wire. Therefore, with a given amount of deflection, the aligner should deliver a lower initial level of force than the ss wire. Additional studies relating force levels to Invisalign® would be beneficial, including clinical studies addressing deformation of aligners in the oral environment over time.

A randomized and controlled clinical trial was performed at UF in 2005 (Wheeler, TT, unpublished data), evaluating the safety, tolerability, and efficacy of recombinant human relaxin during OTM using clear aligners. While this study found no significant difference between the treatment and control groups, concluding that relaxin levels were not related to the rate of OTM, several interesting observations were noted, including: 1) more OTM occurred during the first week vs. the second week of aligner wear for each two-week prescription cycle, 2) the full prescription of the aligners were not expressed, and 3) OTM was highly variable among individuals. These observations have clinical implications and require further research.

Currently patients are instructed to wear each aligner for two weeks, although there is little evidence to support this. Further, the role of aligner degradation on OTM is unknown, but it likely results in a decrease in the magnitude of forces transferred to teeth over time. If material fatigue inhibits aligners from fully expressing their potential (or prescription), it seems reasonable to hypothesize that replacing each aligner after one week with a fresh aligner with an identical prescription may increase the reliability of OTM. Patients and clinicians could benefit from a better understanding of the impact of appliance degradation and fatigue on OTM.

# CHAPTER 2
# METHODS

## Study Design

This study was a prospective single center clinical trial involving subjects with minor incisor malalignment, who were otherwise healthy and intended to undergo comprehensive orthodontic treatment. The design for this study was patterned off of a previous study consisting of 37 subjects designed by the same principal investigator at UF in 2005, which served as the retrospective control group.

Sixteen subjects were enrolled and one dropped out during the screening process prior to initiating treatment, resulting in a sample of 15 subjects ( 6 males and 9 females) between the ages of 18 and 40 years (mean age 25.13). They were in good health and had acceptable malocclusions as defined by the inclusion and exclusion criteria (Table 2-1). Demographic information for the treatment group is compared with the control group in Table 2-2.

The right or left maxillary central incisor was selected as the target tooth based on this tooth not being blocked out by the adjacent teeth. In the event that either tooth would qualify, one was chosen at random.

During this study, subjects were provided with four maxillary aligners, each programmed to move the target tooth 0.5 mm every two weeks. Only bodily movement of the single target tooth in the A-P dimension was programmed (no intrusion, extrusion or rotation). In addition, for the treatment group, four duplicate aligners were fabricated for the replacement of the delivered aligner at the beginning of each odd-numbered week. Therefore, new aligners were dispensed each week (Weeks 0-7). This is in contrast to the control group, where subjects wore only four aligners, each for a period of two weeks. The final time point for data collection, marking the end of the study, was at Week 8.

All study subjects were instructed to wear the aligners full-time. However, they were allowed to remove the appliance when eating, drinking, or brushing their teeth. Compliance was monitored using a daily diary that was completed by the study subjects.

After the conclusion of the study, subjects were treated at the UF graduate orthodontic clinic with Invisalign®.

## Enrollment

To determine subject eligibility, two screening visits were required.

### Screening 1 (Initial Screening)

The purpose of this appointment was to identify potential subjects with malocclusions needing minor incisor alignment and to eliminate those with medical conditions or intraoral problems that were exclusionary.  Potential subjects were allowed to proceed with Screening 2.

### Screening 2 (Second Screening)

The purpose of this appointment was to finalize the subject's eligibility and collect records.  The following procedures were performed: 1) PVS impressions, 2) intraoral and extraoral photographs, and 3) CBCT imaging.  For women, a negative urine pregnancy test immediately prior to radiographic procedures was required.

After the investigator reviewed all information and confirmed eligibility, the subject was enrolled into the study and the target tooth was identified according to the above criteria.

## Study Visits

### Week 0

At the first study visit (Week 0) the first aligner was delivered with instructions to wear full-time except while eating, drinking and brushing. The acceptable visit window for Weeks 0 - 8 was ± one day, and all 15 treatment subjects successfully satisfied this requirement.

### Weeks 1, 2, 3, 4, 5, 6 and 7

At these visits maxillary PVS impressions as well as frontal and occlusal photographs were taken, and the next aligner was delivered.

### Week 8 (Study Termination)

At the final study visit (Week 8) maxillary PVS impressions and final photographs were taken as well as CBCT imaging of the maxilla.

## Collection of Data

Weekly digital models were fabricated from PVS impressions. Models from Weeks 1-8 were then superimposed with the initial model from Screening 2, according to the best fit of the posterior teeth (Figure 2-1), using Align Technology's ToothMeasure® software, version 2.3. The centroid of the clinical crown of the target tooth was established, and the amount of A-P and vertical OTM of the target tooth was then measured for each timepoint relative to baseline. The A-P axis was determined by the direction of programmed OTM in ClinCheck®. Examiner 1 (an orthodontic resident) measured the models of the 15 treatment subjects, and Examiner 2 (a 3rd year dental student) measured the 37 control subjects.

CBCT images were obtained during Screening 2 and Week 8. Using Anatomage's InVivoDental® software, version 4.1, the orientation of these images were adjusted by

Examiner 1 to standardize the A-P axis with the corresponding digital models. Initial and final images were superimposed, registered on the curvature of the palate and best fit of maxillary bony structures. Multiple measurements were obtained (Table 2-3 and Figure 2-2).

Δ U1 (x) refers to the distance between lines drawn through the midpoint of the incisal edges of the superimposed target tooth perpendicular to the A-P axis (the plane of prescribed tooth movement). Δ U1 (s) is the length of the line connecting the midpoint of the incisal edges of the superimposed target tooth. Δ Apex refers to the length of a line connecting the change in apex of the superimposed target tooth. Rotation angle is the angle created by the intersection of lines drawn from the midpoint of the incisal edge to the apex of the target tooth. The apex of this angle is considered the center of rotation. Tooth length refers to the distance from the midpoint of the incisal edge to the apex of the target tooth from the initial x-ray. Crown length is the portion of the tooth length that is coronal to the bone. Bone to C-rot. is the section of tooth length between the center of rotation and a line connecting the most coronal aspect of the faciolingual crestal bone. Δ U1 (o) refers to the A-P change in the midpoint of the superimposed incisal edge of the opposite central incisor, the one that was not the target tooth. From these measurements, additional ratios and measurements were calculated.

A fractal analysis score[3] was calculated from the CBCT for each treatment subject, which was used to determine the quality of the bone. CBCT slices through comparable planes were obtained across all subjects. Images were subjected to histogram equalization using a reference image, and a region of interest (ROI) adjacent to the apex of the target tooth was selected for use on all images. Fractal analyses were carried out for each of the different ROIs using the power spectrum method employed by the TACT® workbench. Thirty-two bit complex floating point representations of the ROIs were cropped, and subject to 2D Fast Fourier transform (FFT), followed by plotting the log of the magnitude versus frequency component that was generated by the FFT. A regression line was fit to this plot, and the slope of this line was used to generate a fractal dimension (FD) for each of the ROIs.

The higher the FD, the higher the morphological complexity at the ultra-structural level of bone. Analyses of FD have been correlated with the strength of bone in previously reported studies.

### Calibration

Examiners 1 and 2 were trained to use the ToothMeasure® software on the same day, and the following measurement protocol was agreed upon: 1) allow the software to ignore teeth according to its "statistical filtering" protocol, 2) always ignore teeth immediately adjacent to the target tooth as well as the target tooth itself, and 3) instruct ToothMeasure® to superimpose the models according to the best fit of the remaining teeth. Interexaminer reliability was determined after separately measuring six randomly selected subjects from the 2005 UF study, with eight superimpositions per subject. Results were identical between Examiners 1 and 2, who later measured superimposed digital models for the treatment and control groups, respectively.

For the CBCT data, Examiner 1 re-measured the following variables on a different day to determine reproducibility: ΔU1 (s), rotation angle, tooth length, and crown length. The intraclass classification coefficient (ICC) of Fliess [4,5] was determined, using R software®,[6] to quantify the strength of relationship between the duplicate measurements. ICC values ranged from 0.90 to 0.99, which demonstrated excellent reliability.

## Statistical Management of Data

The amount of A-P OTM of the target tooth from baseline to Week 8 was assessed for the 15 treatment subjects that completed the study. One subject dropped out after enrollment but prior to initiating OTM and thus had no data to analyze. Model data from the treatment sample was compared with data from the control group with a sample size of 37. The null hypothesis of no difference in OTM from baseline to Week 8 between control group and treatment group was tested, using a two sample t-test with a level of significance set at 0.05. Mixed modeling analysis was used to test the difference between the first week of any given two-week interval vs. the second week, and differences with treatment group over the four two-week cycles.

OTM was quantified using descriptive statistics from CBCT data.

Correlations between tooth movement and possible covariates were analyzed using Pearson correlation coefficients.

Table 2-1. Comparison of demographics of treatment and control groups.

| | Treatment | | | Control | | | |
|---|---|---|---|---|---|---|---|
| | n | Mean ± SD | Range | n | Mean ± SD | Range | p-value |
| Age (yr) | 15 | 25.5 ± 4.8 | 20.5 - 34.9 | 37 | 26.7 ± 5.1 | 18.6 - 40.5 | 0.50* |
| Sex | | | | | | | |
| Male (%) | 6(30) | | | 11(30) | | | 0.52** |
| Female (%) | 9(60) | | | 26(70) | | | |
| Race | | | | | | | |
| White (%) | 8(53) | | | 28(76) | | | 0.08*** |
| Black (%) | 2(12) | | | 5(14) | | | |
| Asian (%) | 3(20) | | | 1(3) | | | |
| Hispanic (%) | 1(7) | | | 3(8) | | | |
| Pac Island (%) | 1(7) | | | 0 | | | |

* Wilcoxon rank sum test

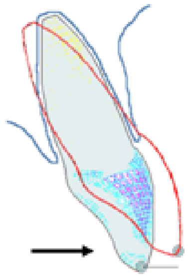
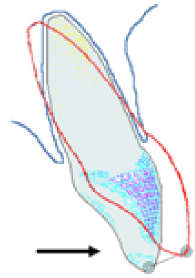
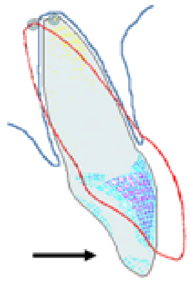
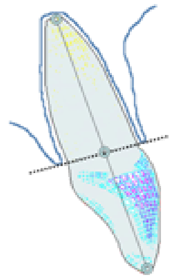
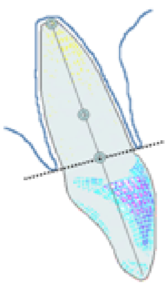
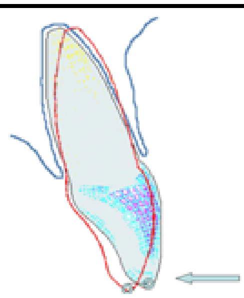
** Fisher exact test

*** White vs. non-white Fisher exact test

Table 2-2. Inclusion and Exclusion Criteria.

| | |
|---|---|
| 1 | Males or females between the ages of 18 and 40. |
| 2 | Must have adult dentition with all upper front teeth present. |
| 3 | Must have at least one upper maxillary central incisor that has sufficient space between it and adjacent teeth to allow AP movement (crown tipping only) of 2 mm. |
| 4 | Must have normal pulp vitality, gingival attachment, papillary bleeding score index (PBS index), and pocket depth. |
| 5 | Must be in good health as determined by medical history. |
| 6 | Must be willing and able to participate. |
| 7 | Must understand and sign a written informed consent form. |
| 8 | Must not have active caries. |
| 9 | Must not be a chronic user of NSAIDS or steroid medication. |
| 10 | Must not have smoked in the last six months. |
| 11 | Women must not be pregnant. |

Table 2-3. Superimposed CBCT measurements. Blue is initial and red is final.

| | | | |
|---|---|---|---|
| Δ U1 (x) |  | Δ U1 (s) |  |
| Δ Apex |  | Tooth length<br>Crown length |  |
| Bone to C-rot. |  | Rotation angle |  |
| *Δ U1 (o)*<br>*(Contralateral)* |  | *Δ U1 (t)*<br>*(Rt and Lt U1s)*<br>*(Δ U1 (x) - Δ U1 (o))* |  |

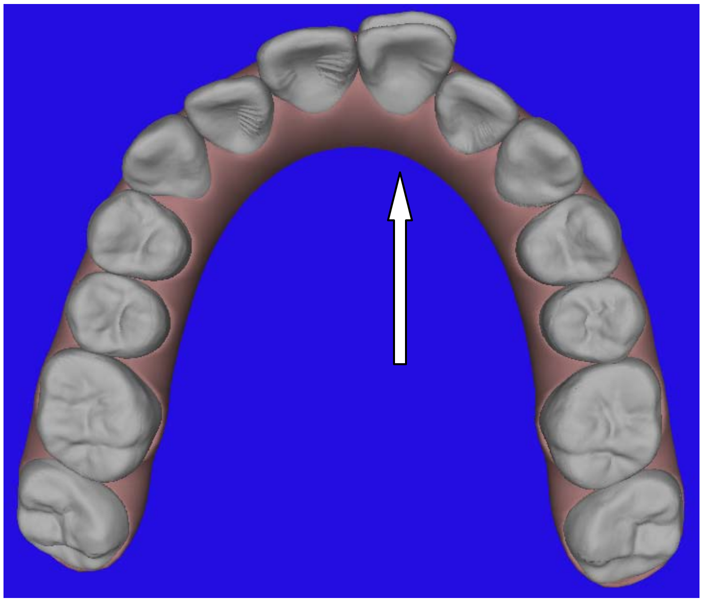
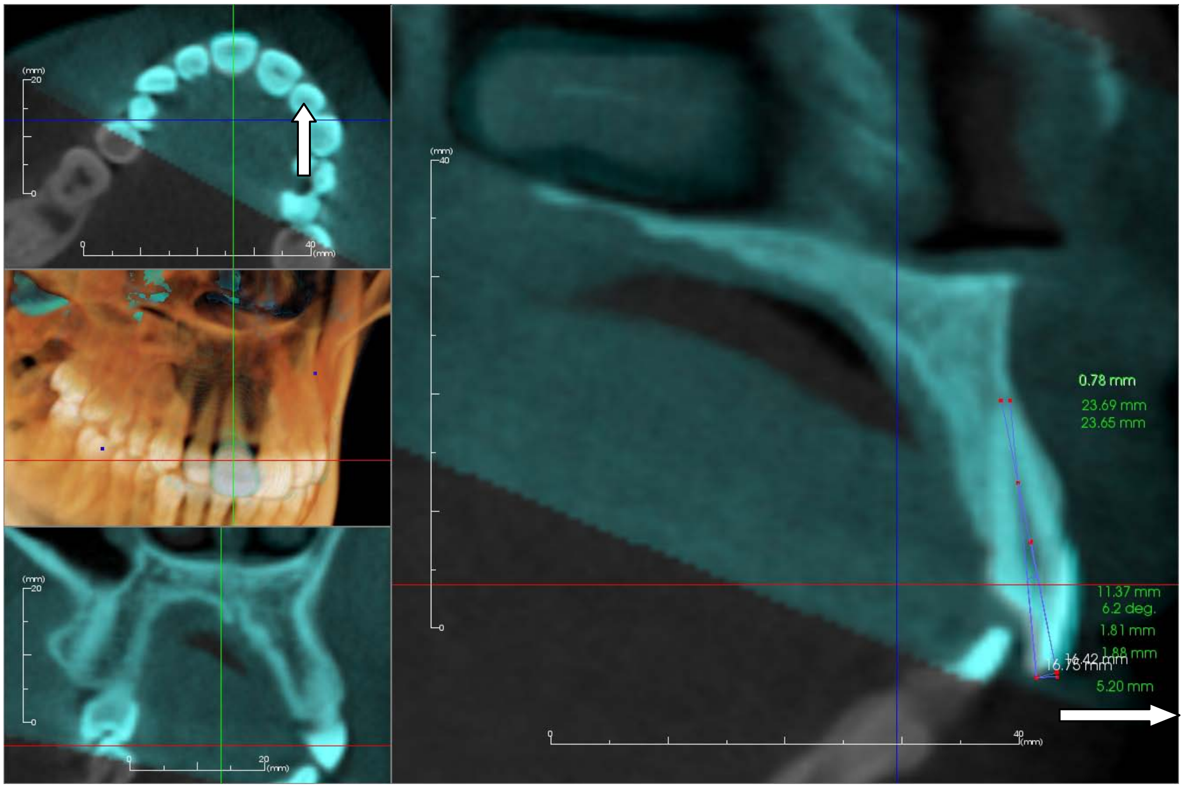
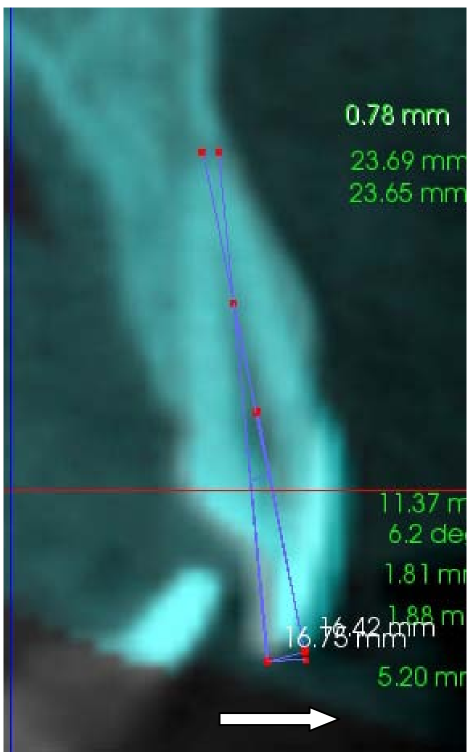


Figure 2-1. Superimposed digital models.




A




B

Figure 2-2. Superimposed CBCT (A) and close-up of target tooth with measurements (B). Gray is initial and blue is final.

# CHAPTER 3
# RESULTS

Results from model measurements are summarized in Table 3-1, and a comparison of mean values for the treatment and control groups is illustrated in Figure 3-1. No overall difference in OTM was detected between the groups, with mean total OTM of 1.11 mm (standard deviation (SD) 0.30) and 1.07 mm (SD 0.33) for the treatment and control groups, respectively ($p=0.72$). Also, no difference was detected in weekly OTM of the treatment vs. control groups overall (Table 3-2) ($p=0.812$) or between any two-week prescription cycle (Table 3-3) (p's=0.176 and 0.297). However, as shown in Table 3-4, 4.4 times more OTM occurred during the first week than the second week of aligner wear ($p<0.001$) after combining the groups.

Measurements from superimposed CBCT images confirmed that the target tooth experienced uncontrolled tipping (Table 3-5). The center of rotation, on average, was located a distance of 41% of the root length apical to the faciolingual crestal bone. The incisal edge of the target tooth moved more than the centroid of the clinical crown in all cases, with a mean of 1.56 mm for Δ U1 (x) compared with 1.1 mm measured from the centroid. Δ U1 (s) had a mean of 1.63 mm, compared with the mean Euclidian mean value of 1.11 mm measured from the centroid of the clinical crown on the models. The apex of the target tooth moved in the opposite direction with a mean of -0.73 mm. The contralateral central incisor experienced a loss of anchorage measured from the incisal edge, with a mean OTM of -0.28 mm.

Mean FD determined from the CBCT of each treatment subject was 1.71 ± SD 0.20. Pearson Correlation Coefficient values between OTM and CBCT measurements are listed in Table 3-6.

Table 3-1. Weekly statistics from treatment and control groups, respectively.

| Tx Group | n | Median | Mean | Std Error | SD | Min | Max |
|---|---|---|---|---|---|---|---|
| Wk 0 | 15 | 0 | 0 | 0 | 0 | 0 | 0 |
| Wk 1 | 15 | 0.240 | 0.239 | 0.0174 | 0.0674 | 0.100 | 0.370 |
| Wk 2 | 15 | 0.310 | 0.297 | 0.0228 | 0.0883 | 0.130 | 0.450 |
| Wk 3 | 15 | 0.430 | 0.458 | 0.0295 | 0.114 | 0.330 | 0.670 |
| Wk 4 | 15 | 0.450 | 0.497 | 0.0418 | 0.162 | 0.230 | 0.770 |
| Wk 5 | 15 | 0.620 | 0.701 | 0.0536 | 0.207 | 0.430 | 1.060 |
| Wk 6 | 15 | 0.770 | 0.793 | 0.0534 | 0.207 | 0.530 | 1.130 |
| Wk 7 | 15 | 1.040 | 1.033 | 0.0648 | 0.251 | 0.530 | 1.420 |
| Wk 8 | 15 | 1.160 | 1.108 | 0.0768 | 0.297 | 0.350 | 1.460 |

| Control | n | Median | Mean | Std Error | SD | Min | Max |
|---|---|---|---|---|---|---|---|
| Wk 0 | 37 | 0 | 0 | 0 | 0 | 0 | 0 |
| Wk 1 | 36 | 0.210 | 0.206 | 0.0122 | 0.0735 | 0.0300 | 0.320 |
| Wk 2 | 36 | 0.240 | 0.234 | 0.0122 | 0.0735 | 0.0500 | 0.390 |
| Wk 3 | 37 | 0.440 | 0.445 | 0.0228 | 0.138 | 0.100 | 0.680 |
| Wk 4 | 36 | 0.530 | 0.495 | 0.0255 | 0.153 | 0.0700 | 0.790 |
| Wk 5 | 36 | 0.775 | 0.726 | 0.0380 | 0.228 | 0.120 | 1.100 |
| Wk 6 | 36 | 0.830 | 0.737 | 0.0416 | 0.250 | 0.0700 | 1.100 |
| Wk 7 | 37 | 1.080 | 1.009 | 0.0519 | 0.316 | 0.100 | 1.410 |
| Wk 8 | 37 | 1.180 | 1.072 | 0.0536 | 0.326 | 0.220 | 1.550 |

Table 3-2. Mixed modeling comparing mean OTM per week from baseline to Week 8 for treatment vs. control group.

| Group | Mean ± SD | P value (t-test) |
|---|---|---|
| Treatment | 0.14 ± 0.11 | 0.812 |
| Control | 0.14 ± 0.15 | |

Table 3-3. Mixed modeling comparing the mean magnitude of OTM per week expressed during each two-week prescription cycle.

| Group | Interval | Mean/Wk ± SD | P value |
|---|---|---|---|
| Treatment | Week 1-2 | 0.15 ± 0.11 | 0.176 |
| | Week 3-4 | 0.10 ± 0.09 | |
| | Week 5-6 | 0.15 ± 0.11 | |
| | Week 7-8 | 0.16 ± 0.13 | |
| Control | Week 1-2 | 0.12 ± 0.11 | 0.297 |
| | Week 3-4 | 0.13 ± 0.13 | |
| | Week 5-6 | 0.13 ± 0.17 | |
| | Week 7-8 | 0.16 ± 0.19 | |

Table 3-4. Mixed modeling comparing OTM during the first week vs. second week for the treatment and control groups, both separately and combined.

| Group | Interval | Mean ± SD | P value |
|---|---|---|---|
| Treatment | 1st week | 0.21 ± 0.09 | < 0.0001 |
| | 2nd week | 0.07 ± 0.08 | |
| Control | 1st week | 0.23 ± 0.13 | < 0.0001 |
| | 2nd week | 0.04 ± 0.11 | |
| Total | 1st week | 0.22 ± 0.12 | < 0.0001 |
| | 2nd week | 0.05 ± 0.10 | |

Table 3-5. CBCT measurements from treatment group.

| Variable | n | Mean | SD | Max | Min |
|---|---|---|---|---|---|
| Δ U1 (x) | 15 | 1.56 | 0.38 | 2.02 | 0.80 |
| Δ U1 (s) | 15 | 1.63 | 0.40 | 2.09 | 0.80 |
| Δ Apex | 15 | -0.73 | 0.26 | 1.32 | 0.39 |
| Tooth Length | 15 | 24.87 | 2.02 | 30.32 | 21.67 |
| Crown Length | 15 | 12.27 | 0.74 | 13.27 | 10.84 |
| Bone to C-rot. | 15 | 5.14 | 1.25 | 7.7 | 2.9 |
| Δ U1 (o) | 15 | -0.28 | 0.16 | 0.52 | 0 |
| Δ U1 (t) | 15 | 1.85 | 0.36 | 2.4 | 1.08 |

Table 3-6. Pearson Correlation Coefficient of Week 8 OTM vs. Biologic Variables.

| Variable | n | R | P value |
|---|---|---|---|
| Age | 15 | -0.25 | 0.37 |
| Crown/Root ratio | 15 | -0.01 | 0.97 |
| Fractal Dimension | 15 | 0.38 | 0.10 |

Table 3-7. Comparison of Model and CBCT mean A-P OTM.

| | n | Mean | Max | Min | SD |
|---|---|---|---|---|---|
| Model (x) | 15 | 1.09 | 1.44 | 0.35 | 0.28 |
| Δ U1 (x) | 15 | 1.56 | 2.02 | 0.8 | 0.38 |
| Δ U1 (t) | 15 | 1.85 | 2.4 | 1.08 | 0.36 |
| Ratio (x/x) | 15 | 0.7 | 0.92 | 0.44 | 0.11 |
| Ratio (x/t) | 15 | 0.59 | 0.73 | 0.32 | 0.1 |

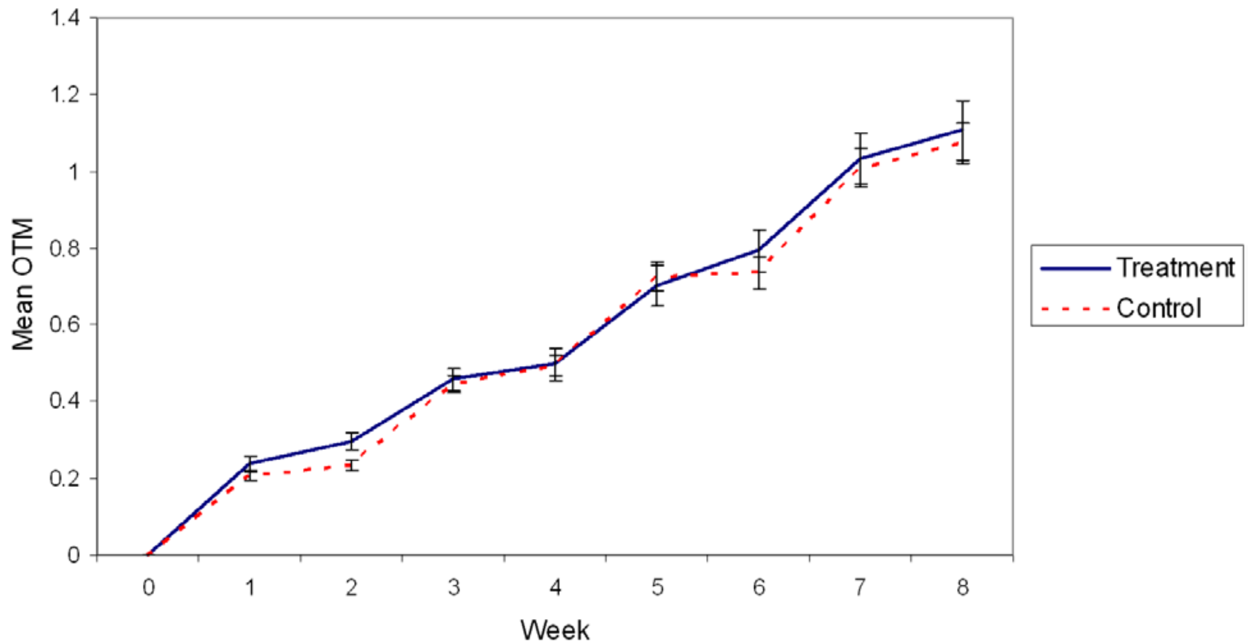


Figure 3-1. Mean weekly OTM with Std. Error.

# CHAPTER 4
# DISCUSSION

This study reinforced previous findings that the vast majority of OTM during any 2-week aligner prescription cycle occurs during the first week of the cycle. The target tooth in this eight-week study did not undergo the classic cycle of tooth movement described by Krishnan et al.[7] This my be due to the two-week activation cycle or the inability of the removable polyurethane aligners to produce a continuous force,

Due to incomplete expression during the previous seven weeks, the amount of target tooth activation after delivery of the eighth aligner was in excess of 1 mm, according to model data. This likely resulted in the tooth feeling a greater force during the last week than after delivery of the first and second aligners, when the amount of activation was 0.5 mm or less. However, significantly less OTM occurred at Week 8 than Week 1, and there was no significant difference in the amount of OTM observed at Week 8 and Week 2. This suggests that the discrepancy in the amount of OTM achieved during the first and second week of each prescription cycle cannot be explained by force magnitude. This is further supported by our finding that the use of fresh aligners did not increase the amount of OTM.

Although bodily protraction of the target tooth was programmed, uncontrolled tipping resulted, which has clinical implications. More specifically, the final result will be different from Clincheck®, and aligner retention and tracking may be negatively affected. When clinicians attempt to move maxillary incisors in the A-P dimension with aligners, allowing for vertical changes of the incisal edges may make treatment more predictable, which could reduce the need for midcourse modifications and make treatment more efficient. The amount of relative intrusion and extrusion to program can be determined by estimating the location of the center of rotation of the teeth (determined to be approximately 41% of the root length apical to the faciolingual crestal bone).

According to model data, the full prescription was not expressed in any of the 52 subjects. In fact, the mean OTM for both groups was only 1.1 mm, or 55% of the prescription. It is important to remember that the prescribed amount of OTM was twice the maximum rate per aligner currently prescribed by Invisalign®. It is possible that a greater percentage of the prescription might be achieved if the maximum two-week activation was decreased to 0.25 mm instead of 0.5 mm. This is currently being studied.

The discrepancy between the amount of OTM prescribed and that achieved may be partially explained by the method of measurement used in this study as well as the uncontrolled tipping that occurred. The largest amount of OTM recorded from baseline to Week 8 from model data was 1.44 mm, or 72% of the prescription. This same subject had 1.98 mm of OTM from baseline to Week 8 when measured from the incisal edge of the target tooth of superimposed CBCT images. See Table 3-7 comparing model and CBCT mean OTM values. Given this information, one would not expect 100% of the prescription at the centroid of the crown to be fulfilled since OTM at the incisal edge was already fully achieved.

One must also consider anchorage loss of the contralateral central incisor when interpreting this data. The prescribed protraction of the target tooth relative to the contralateral central incisor at Week 8 was two mm for each subject, and the difference between Δ U1 (o) and Δ U1 (x), or Δ U1 (t), indicates that a mean of 1.85 mm of this two mm distance was actually fulfilled, an average of 92.3% of the prescription. In addition, eight of the 15 subjects showed a total OTM greater than 1.9mm, which indicates that OTM at the incisal edge of these subjects was nearly fully expressed.

The measurement method explains a portion of the discrepancy in model data between programmed and actual OTM. However, tremendous variation was reported among subjects, and several target teeth did not achieve their full prescription at the incisal edge. Some discrepancy among this subset may be explained by lack of compliance. However, from a biologic perspective, it is likely that a subset of subjects did not have the capacity to keep up with the prescribed rate of OTM. According to Krishnan et al.,[8] several systemic factors can influence rates of OTM, and some were specifically excluded from this study. Others that were not controlled, such as sex, age, bone quality, tooth length, and the location of the center of resistance (determined by root length, root width, and bone height)[1,9] may have been a factor.

The result of the exploratory data analysis attempting to correlate several of these biologic variables with OTM was statistically insignificant with low powers of explanation. Some trends were noted, however, and future research with larger sample sizes will be necessary to explore these findings.

There was considerable variability of OTM in this study, which is a problem that practicing orthodontists often encounter. Improving the ability to identify patients who are unlikely to respond well to treatment would be beneficial for the profession and should be a focus of ongoing research. Regarding OTM using clear aligners, methods of altering treatment to compensate for patients who may not respond as well to OTM might be: 1) establishing realistic expectations, 2) spreading treatment over additional aligners, thus decreasing the programmed rate of tooth movement, and 3) programming over-correction into Clincheck®. We hope to further examine these issues in future studies.

# CHAPTER 5
# CONCLUSION

This single center clinical trial examined OTM using clear aligners. No significant difference was found in the amount of OTM between those who wore the same aligner for two weeks vs. those who changed to a fresh aligner after one week. Therefore, the reduction in the amount of OTM seen during the second week of aligner wear was likely not due to material fatigue. Other variables that could affect tooth movement such as age, gender, root location and bone quality were examined. However, subject numbers were too low to make any conclusions.

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# BIOGRAPHICAL SKETCH

Carl T. Drake was born in Bloomington, IL and raised in El Paso, IL where he graduated from El Paso High School in 1999. He received a Bachelor of Science in Business Administration with a concentration in entrepreneurship from the University of Illinois in 2003. He continued his education at Indiana University in Indianapolis and earned a Doctorate of Dental Surgery degree in 2007. He is expected to receive a Master of Science in Dental Sciences as well as a Certificate in Orthodontics from the University of Florida in the spring of 2010.

Carl plans on living and working in Bloomington-Normal, IL following graduation. He has been happily married to his wife, Kristen, since 2003, and they have two children, Benjamin and Ella.