A Comparison of Digital Intraoral Scanners and Alginate Impressions:
Time & Patient Satisfaction

THESIS

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Abstract

Introduction: Impressions play an important role in dentistry and its specialties. Recent technological advances have made intraoral scans and digital models a possibility, and a promising alternative to conventional alginate impressions. Several factors should be examined when considering an intraoral scanner, including patient acceptance and efficiency. The objectives of this study were to assess and compare patient satisfaction and time required among two intraoral scanners and conventional alginate impressions.

Methods: An initial pilot study was completed to create a valid and reliable survey instrument which would measure three areas of patient satisfaction with the impression experience. Following the survey development, the questionnaire was administered to orthodontic patients receiving one of three types of impressions, and the time required to obtain the impressions was recorded.

Results: Reliability was evaluated with ICC values for 17 paired questionnaires, and all questions were found to be reliable (ICC ≥ 0.65). For the main study, 180 subjects completed timed impressions and surveys. Data indicated that subjects receiving intraoral scans preferred the digital impressions while subjects receiving alginate impressions were neutral regarding impression preference, and that efficiency varied based on impression method.

Conclusions: Intraoral scanners are accepted by orthodontic patients, and they have comparable efficiency to conventional impression methods depending on type of scanner.
Dedication

This document is dedicated to my family who has always provided love and support throughout my education, and especially to my husband David for his unconditional love, encouragement, and patience.
Acknowledgments

I would like to first express gratitude to my thesis committee for all of their guidance and hard work. Dr. Deguchi was the source of many ideas for the project, but he was always open to my thoughts and suggestions; he continually offered valuable advice and support. Dr. Firestone had excellent vision and constructive recommendations. His good humor was always appreciated, and his confidence in me had a great impact. Dr. Beck was instrumental in the study; he knows everything about statistics, and patiently explained the concepts, tests, and data analyses to me (more than once). I am sincerely grateful for all of you.

The full- and part-time orthodontic faculty at OSU have been incredible to work with and learn from. I appreciate your passion for the profession and your dedication to teaching the residents. I would especially like to thank Drs. Wade and Hutta for sacrificing their time and volunteering their private practices to help collect data for this study- I could not have done it without you!

I would like to thank my co-residents for their friendship and support. Their help in recruiting patients was invaluable, and their camaraderie made three years of residency truly enjoyable. Also, I could not have completed the study without the expertise of the OSU Orthodontic clinic staff - your expertise with impressions was helpful, and I very much appreciate your willingness to help me.

Finally, I wish to thank the Delta Dental Foundation for their financial support with this project.
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CHAPTER 1

Introduction

Impressions have been used in the dental field since the latter part of the eighteenth century, and still hold a place of great importance in the practice of dentistry. Throughout the past two centuries, the modes of making dental impressions have greatly evolved, including molded wax, compound, reversible and irreversible hydrocolloids, and synthetic rubbers. The 20th century showed remarkable advances in technology, and digital impressions for use in dentistry came about in the 1980’s. In the decades following, and up to modern times, digital impression techniques have continued evolving and their uses have broadened. In recent years, interest in three-dimensional imaging and digital scanning has increased greatly. Digital impressions and 3D models have a wide range of application in the dental field and dental specialties. Uses of digital models for orthodontics include analysis teeth and occlusion, treatment simulation, appliance design and production, and treatment effects1.

One reason digital impression technology has not been fully integrated into modern practices is due to the endurance of conventional impression methods. These techniques include hydrocolloid and elastomeric materials, such as alginate, polyether, and polyvinyl siloxane. The advantage of these materials is that they are accurate, well accepted2–3, and are traditionally inexpensive. However, these types of impressions are not always favored by patients and have been reported as unpleasant and burdensome4–5.
Additionally, these conventional impression methods require inventory and stocking of raw materials as well as storage space for the plaster models. Digital impressions and the 3-dimensional models they create have numerous advantages over traditional alginate and plaster models, including more efficient storage and retrieval, increased diagnostic versatility, superior durability, easier transferability, and decreased processing time\(^6\).

With the development of digital impression technology and their reported advantages, one major concern has been the accuracy of the impression and the 3-dimensional digital model produced. Prior studies have been performed to evaluate the accuracy of 3D models, and have shown that they are comparable to plaster models using both linear and angular measurements as well as shell-shell deviation and arch-registration measurements\(^7\)\(^-\)\(^11\). As evidence has supported the accuracy of digital impression techniques, their popularity in orthodontics is on the rise. Digital models are compatible with many laboratories, allowing efficient digital communication while still allowing quality fabrication of restorations, prostheses, and appliances. Since the advent of 3-dimensional scanning in dentistry, several dental and orthodontic suppliers have started producing digital scanners and comprehensive software analysis programs that provide many functions\(^12\). These functions can simplify procedures that were traditionally done using physical models such as dental analysis and diagnosis, occlusal setups, and treatment predictions. The digital software can also offer new procedures that were previously impossible with plaster casts, such as the ability to overlay models at different timepoints, allowing visualization of tooth movements and treatment outcomes.
As various dental and orthodontic companies have been producing intraoral scanning systems, there is an ever-changing market of scanners available. Digital scanners can differ in acquisition method as well as in the unit’s weight, size, and speed. The methods in which scanners acquire the intraoral impression are triangulation, active wavefront sampling (AWS), parallel confocal, accordion fringe interferometry (AFI), and three-dimensional in-motion video\textsuperscript{12, 13}. Triangulation uses the reflections of laser light to measures angles and distances, and these measurements result in a 3D impression.

Because light reflection needs to be uniform and accurate, an opaque layer of powder is used to coat the surfaces being scanned; titanium dioxide is a common agent used for tooth-powdering. AWS uses multiple sensors to detect blue light and image focus, resulting in measurements used to recreate a 3D image; this system requires a light dusting of opaque powder. The parallel confocal technique uses laser light focused through a small hole to filter out-of-focus light, and takes images in “slices” of the object which can then be stitched together to reconstruct the image. While this “point-and-stitch” reconstruction is accurate, it takes longer to generate images. AFI uses multiple sources of light to create patterns, which change based on the object being scanned; a high-definition video camera records data from the impression and measurements are made based on the light patterns. Three-dimensional in-motion video utilizes three small video cameras to capture images of the object as well as reflected light to measure distances. A light layer of opaque powder is also required in this method. Because AFI and 3D in-motion methods use high-definition cameras to take images in real time, these methods are faster than other techniques that reconstruct images.
Examples of currently marketed intraoral scanning systems include the iTero Element (Align Technology, San Jose, CA), TRIOS 3 (3Shape A/S, Copenhagen, Denmark), True Definition (3M ESPE, St. Paul, MN), Cerec AC OmniCam (Sirona Dental Systems, Bensheim, Germany), CS3600 (Carestream Health, Rochester, NY), and PlanScan (Planmeca/E4D Technologies, Richardson, TX). The iTero Element uses the parallel confocal imaging technique, or “scan in motion,” and has a scan capture time of 40-50 milliseconds, capturing 6000 frames/second or 20 scans/second. This method does not require powdering. The scanning wand weighs 1.1 pounds, with dimensions of 2 x 3 x 13 inches. The Element system consists of a combined touchscreen monitor processing unit and a scanning wand on a rolling unit, or a countertop mount. The TRIOS 3 scanner uses ultrafast optical sectioning with a capture time of 3000 2D images/second, or 1000 3D images/second; this system also does not require powder. The company offers the wand in either a pen or handle style, and it weighs 0.75 pounds. The scanning unit also offers choices, and can include a touchscreen and processor on a rolling cart, can be used with the POD solution to be connected to a laptop or notebook, or can be integrated into the dental chair as would a suction and handpiece. The True Definition scanning system uses blue light and 3D video in-motion technology to capture images, and it does require opaque powder to be used. The scanner wand weighs about 0.5 pounds. The unit includes a touchscreen monitor, a scanning want, and a central processing unit on a rolling cart. The Cerec AC OmniCam system is one of the longest-running scanning systems, and uses continuous color imaging to capture scans. It does not require powdering, and also comes in a rolling unit, with the wand weighing 0.75
pounds. The CS3600 scanner uses intelligent matching system to capture a continuous
scan. It does not require powder, and comes as a scanning wand which weighs about 0.65
pounds, and can be connected to an existing computer or laptop. The PlanScan system
utilizes blue light and laser video capture, and captures >10 datasets/second. It is a
powder-free system, and the wand and stand connect to an existing computer or laptop.
The wand measures 1.9 x 2.1 x 10.9 inches, and weighs 1.2 pounds.

The costs of these systems varies\(^\text{16}\), and some require software fees and ongoing
management services. Reported costs range from $16,000 to $42,000 for the systems.
Some of the intraoral scanning systems require annual or monthly data plans, which
range from $200 to $360 per month or $1000 to $6000 per year. Other costs include
disposable tips and retractors, while some systems offer tips that can be sterilized. Most
current scanning systems permit STL file export, allowing easy communication with
most dental and orthodontic labs. The digital files may be stored with a hard drive, while
some systems offer Cloud storage. All of these factors should be considered and weighed
before making an investment.

Given that the accuracy of digital models has been proven and they hold several
advantages over conventional impressions, the current topic in research is the acceptance
and utilization of intraoral scanners in everyday dental and orthodontic practice. When
deciding how to incorporate an intraoral scanner into daily practice and what type of
scanner to use, a practitioner may consider several factors including performance, patient
comfort, efficiency, ease of use, portability, features/options, vendor company,
compatibilities, and cost; a number of these have been discussed above. Data regarding
some of these key aspects of digital scanners are lacking, and what has been reported
gives conflicting results. Some recent investigations report patients’ preference for
intraoral scans when compared to conventional impression techniques, but the amount of
time required for digital versus conventional impressions varied\textsuperscript{17-19}. However, these
studies were completed on an adult population, utilized impression materials other than
alginate, and involved implant and prosthetic restorations rather than orthodontic
treatment. Other investigations have been completed in mixed age and young orthodontic
populations, with one study showing the majority of subjects preferred alginate
impressions to digital\textsuperscript{10}, and another showing subject preference for digital impressions to
alginate\textsuperscript{20}.

Methods used to gather information about patient satisfaction and preferences
typically include surveys or questionnaires. Various types of surveys can be utilized for
psychometric measurements, and the most commonly used measurement scales are the
Likert scale and visual analog scale (VAS), both of which have been found to be
reliable\textsuperscript{21}. The Likert scale provides multiple pre-determined categories for the subject to
select, such as “strongly agree, agree, neutral, disagree, and strongly disagree.” It is
measured with ordinal numbers, where each answer choice is assigned a nominal value.
However, this type of scale forces the subject to select one choice, with no consideration
for the varying levels of sentiment; also, the space between each choice cannot be defined
as equal. The result of a Likert scale is that while it provides some measure of subject
opinion, it cannot measure the true attitude or belief of the subject. The VAS is a linear
scale, anchored with two opposing words or extremes at either end, in which the subject
places a mark anywhere along the scale according to the level of their sentiment. The VAS responses are measured as continuous data, and therefore a wider range of statistical methods can be used in analysis. With the continuous nature of the VAS, subjects can place a mark anywhere along the scale, allowing for expression of true attitude or belief. The VAS type of response has been recommended in use with applied research, and is often used when studying pain. Because it has been suggested that VAS survey questions have better responsiveness and sensitivity, analyzing patient satisfaction with impressions using this type of questionnaire will provide useful information to the dental and orthodontic community.

Along with expanding the knowledge of some aspects of intraoral scanners and aiding orthodontists’ in their decision to utilize this technology, there are other possible implications with this research. Improvement of patients’ satisfaction with commonplace procedures during dental or medical interventions can result in increases in patient compliance and accession to available medical and dental treatments\textsuperscript{22-24}. This may be especially true in patients who may have fear or anxiety related to healthcare. Due to the limited data and controversial findings from studies examining patients’ opinions of intraoral scans, more information is needed to evaluate patient satisfaction and preference for different impression types.

Therefore, the aims of this study were to assess what we believe to be the most important factors related to digital scanners: patient acceptance and impression efficiency. This study compared two of the currently marketed digital intraoral scanners with each other and with alginate impressions. The intraoral scanners used were the iTero
Element (Align Technologies, San Jose, Calif) and the Trios Color (3Shape, Copenhagen, Denmark). For each impression method, patient satisfaction was measured using a visual-analog survey, and the time required to complete a full-mouth impression was recorded.
CHAPTER 2: 
Materials and Methods

Approval to conduct this study was obtained from the Ohio State University institutional review board, and informed consent was obtained from all participants. A search of relevant research was completed to find an existing survey instrument to evaluate patient satisfaction with impression techniques, and no such instrument had been developed. A survey was designed to test three areas of patient satisfaction regarding the impression experience: comfort, time, and novelty. The proposed survey was administered to a group of orthodontic practitioners, technicians, and patients to confirm validity of the questions. After adjustments and corrections were made to the survey instrument, the finalized survey consisted of seven statements with a 100-mm visual analog scale (VAS) below each statement (Figure 1). The scale was anchored with “agree,” and “disagree.” The survey also included questions to determine if the patient had previous experience with impressions.

Next, a pilot study was undertaken to establish reliability of the instrument. Seventeen subjects were recruited from the Ohio State University College of Dentistry staff, students, and residents. Each participant had either a digital or alginate impression made, followed by administration of the survey; three to four days following the impression, each participant completed an identical second survey. The surveys were
measured and analyzed, and the results from the two timepoints compared to assess reliability of each individual question (Table 2).

Circle which type of impression you had today: Digital / Alginate

Have you had any type of impression before today? Yes / No  If Yes, which type? ________________

Please place a straight line on the scale according to your level of agreement.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Agree</th>
<th>Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Having impressions made is comfortable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. The impression was painless</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. The impression made my mouth dry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Having the impression made was faster than I expected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. The technician that made my impression was skilled</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. I think having new technology at an orthodontic office is important</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. I would rather go to an orthodontist who uses digital models than traditional alginate &amp; plaster models</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. Survey instrument
After the survey instrument was determined to be both valid and reliable, the main study was initiated. The impression methods were categorized into four groups: three digital intraoral scanner groups and one alginate group. The subjects were recruited from three orthodontic practices, each using a different digital intraoral scanner and one using alginate impressions as well. Inclusion criteria specified that they be healthy, English-speaking subjects seeking orthodontic treatment or actively undergoing orthodontic treatment; there were no restrictions for age, gender, or race. Patients were excluded if they had a history of mental disabilities, cleft lip or palate, or other craniofacial anomalies or syndromes.

A total of 180 patients were enrolled: 60 in the iTero group, 60 in the 3Shape group, and 60 in the alginate group. The participant population consisted of 104 females and 76 males, with median age of 15 years (IQR=13-20) and age range of 8-56 years. The distribution of participant age by group is summarized in Table 1.

<table>
<thead>
<tr>
<th>Group</th>
<th>Median age</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>iTero</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>3Shape</td>
<td>15</td>
<td>7.5</td>
</tr>
<tr>
<td>Alginate</td>
<td>17</td>
<td>9</td>
</tr>
<tr>
<td>Combined</td>
<td>15</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 1. Age data by impression group and combined subject population

Each patient had either a digital intraoral scan or alginate impression completed by an expert operator trained and experienced in the specific impression technique used. The scanning protocol was applied according to the manufacturers’ recommendations.
For each intraoral scan with either the iTero Element (Figure 2) or 3Shape Color (Figure 3), the time required to complete a full mouth scan and bite registration was recorded; any verbal explanation or isolation placement was not included in the recorded time. Alginate impressions were obtained with a fast-setting 120-hour alginate material (imprEssix Color Change; DENTSPLY, York, Pennsylvania) and standard plastic impression trays. For each impression, the time required to mix the material and complete a full-mouth (maxillary and mandibular arches) impression was recorded. Immediately following the impression procedure, each participant was asked to complete the VAS survey described above, and return it before the end of the appointment. Each millimeter VAS score was measured to the nearest 0.5 millimeter, and medians and interquartile ranges were calculated for each response.
Figure 2. iTero Element intraoral scanning system

Figure 3. 3Shape Color intraoral scanning system
**Statistical Analyses**

The reliability of the survey instrument was assessed using the data from the pilot study to measure intraclass correlation coefficients for each survey question.

Sample size calculations were completed prior to data collection. With a non-directional alpha risk of 0.05 and assuming a standard deviation of 24\(^{25}\), a sample size of 50 subjects would allow a detection of a difference of ±14 mm on the VAS scale with a power of 0.823. To account for participant dropout and the possibility of using a non-parametric data analysis, we added 20% to the \(n\) of 50, yielding a sample size of 60 per group.

As the assumptions of parametric statistical analyses were not met, the data were analyzed using non-parametric tests. Medians and quartile ranges were calculated for subject gender, age, previous expression experience, impression time requirement, and each survey question. These data were analyzed statistically with the non-parametric Dwass, Steel, Critchlow-Flinger method multiple comparison analysis with a simultaneous P-value adjustment, and \(<.05\) as the level for statistical significance. The data analysis for this paper was generated using [SAS/STAT] software (Version 9.4 of the SAS System for X64_7PRO platform. Copyright © 2002-2012 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA).
CHAPTER 3:

Manuscript

A Comparison of Digital and Alginate Impressions: Time & Patient Satisfaction

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ABSTRACT

Introduction: Recent technological advances have made intraoral scans and digital models a possibility, and a promising alternative to conventional alginate impressions. Several factors should be examined when considering an intraoral scanner, including patient acceptance and efficiency. The objectives of this study were to assess and compare patient satisfaction and time required among two intraoral scanners and conventional alginate impressions.

Methods: An initial pilot study was completed to create a valid and reliable survey instrument which would measure three areas of patient satisfaction with the impression experience. A visual analogue scale (VAS) survey was developed and administered to 180 orthodontic patients receiving one of three types of impressions (iTero Element intraoral scan, n=60; TRIOS Color intraoral scan, n=60; conventional alginate impression, n=60), and the time required to obtain the impressions was recorded.

Results: Reliability was evaluated with ICC values for 17 paired questionnaires, and all questions were found to be reliable (ICC ≥ 0.65). For the main study, 180 subjects completed timed impressions and surveys. Data indicated that subjects receiving intraoral scans preferred the digital impressions while subjects receiving alginate impressions were neutral regarding impression preference, and that efficiency varied based on impression method.

Conclusions: Intraoral scanners are accepted by orthodontic patients, and they have comparable efficiency to conventional impression methods depending on type of scanner.
INTRODUCTION

Orthodontists frequently use dental models for diagnostic and treatment planning purposes such as evaluation of tooth positions and occlusal relationships, space assessment, simulation of tooth and jaw movements, appliance design and fabrication, and treatment effects\(^1\). Methods of making dental impressions have greatly evolved over the past several decades; in recent years, dental models have been conventionally made using alginate impressions and plaster casts. However, current interest in three-dimensional and digital technology in the medical and dental fields has led to the development of three-dimensional scanning and digital models. Advantages of digital models include more efficient storage and retrieval, increased diagnostic versatility, easier transferability, superior durability, and decreased processing time\(^6\).

With the development of digital impression technology and their reported advantages, one major concern has been the accuracy of the impression and the 3-dimensional digital model produced. Prior studies to evaluate the accuracy of 3D models have shown that they are comparable to plaster models using both linear and angular measurements as well as shell-shell deviation and arch-registration measurements\(^7\)-\(^11\). With evidence supporting the accuracy of digital impression techniques, their adaptation in orthodontic practices is increasing. Nevertheless, intraoral scanning has not been fully integrated into orthodontic private practices due to the endurance of conventional impression methods. The advantages of conventional materials is that they are accurate,
well accepted\textsuperscript{2, 3}, and are traditionally inexpensive. However, these types of impressions are not always favored by patients and have been reported as unpleasant and burdensome\textsuperscript{4, 5}. Additionally, these conventional impression methods require inventory and stocking of raw materials as well as storage space for the plaster models. A number of dental and orthodontic suppliers have produced digital scanners\textsuperscript{12}, and some provide high-tech software analysis programs that allow operators to complete model analysis and diagnosis, occlusal setups, treatment predictions, and evaluation of treatment outcomes. Digital models are also compatible with many laboratories, allowing efficient digital communication while still providing quality fabrication of restorations, prostheses, and appliances.

The current topic in research is the acceptance and utilization of intraoral scanners. When deciding how to incorporate an intraoral scanner into daily practice and what type of scanner to use, a practitioner may consider several factors including performance, patient comfort, efficiency, ease of use, portability, features/options, vendor company, compatibilities, and cost. Data regarding some of these key aspects of digital scanners are lacking, and what has been reported gives conflicting results\textsuperscript{10, 20, 27}.

Therefore, the aim of this study was to assess what we believe to be the most important factors related to digital scanners: patient acceptance and impression efficiency. This study compared two of the currently marketed digital intraoral scanners with each other and with alginate impressions. After exploring the intraoral scanners available and those most frequently used by orthodontists\textsuperscript{12}, we chose to include the iTero Element (Align Technologies, San Jose, Calif) and the Trios Color (3Shape, Copenhagen,
Denmark). For each impression method, patient satisfaction was measured using a visual-analog survey, and the time required to complete a full-mouth impression was recorded. The specific objectives of this study were to develop a valid and reliable instrument to assess patient satisfaction with impression experience, to sample orthodontic patients regarding satisfaction with differing impression types, and to compare the time required to obtain different methods of impressions. The null hypotheses include the following:

1. Orthodontic patients will have no significant difference in satisfaction between the three impression methods

2. The time required to obtain an orthodontic impression will not be significantly different between the three impression methods

MATERIALS AND METHODS

Approval to conduct this study was obtained from the Ohio State University institutional review board. Informed consent was obtained from legal guardians and adult subjects, and assent was obtained from minor subjects.

A survey was designed to test three areas of patient satisfaction regarding the impression experience: comfort, time, and novelty. The proposed survey was administered to a group of orthodontic practitioners, technicians, and patients to confirm validity of the questions. After adjustments and corrections were made to the survey instrument, the finalized survey consisted of seven statements with a 100-mm visual analogue scale (VAS) below each statement anchored with “agree” and “disagree.” The
survey also included questions to determine if the patient had previous experience with impressions.

Next, a pilot study was undertaken to establish reliability of the instrument. Seventeen subjects were recruited from the Ohio State University College of Dentistry, and each had an impression made and completed the survey. Three to four days following the impression, each participant completed an identical second survey. The surveys were measured and analyzed, and the results from the two timepoints compared to assess reliability of each individual question.

After the survey instrument was determined to be both valid and reliable, the main study was initiated. Subjects were recruited from the Ohio State University orthodontic residency practice and a private orthodontic practice in Columbus, Ohio to undergo either an intraoral scan or an alginate impression. Inclusion criteria for participants specified that they be healthy, English-speaking subjects seeking orthodontic treatment or actively undergoing orthodontic treatment; there were no restrictions for age, gender, or race. Patients were excluded if they had a history of mental disabilities, cleft lip or palate, or other craniofacial anomalies or syndromes. A total of 180 orthodontic patients were included in the study: 60 subjects had an intraoral scan with the iTero Element, 60 had an intraoral scan with the Trios Color, and 60 had alginate impressions. The participant population consisted of 104 females and 76 males, with median age of 15 years (IQR=13-20) and age range of 8-56 years. The distribution of participant age by group is summarized in Table 1.
Each subject had either a digital intraoral scan or alginate impression completed by an operator trained and experienced in the specific impression technique used. The scanning protocol was applied according to the manufacturers’ recommendations. For each intraoral scan with either the iTero Element or 3Shape Color, the time required to complete a full mouth scan and bite registration was recorded; any verbal explanation or isolation placement was not included in the recorded time. Alginate impressions were obtained with a fast-setting 120-hour alginate material (imprEssix Color Change; DENTSPLY, York, Pennsylvania) and standard plastic impression trays. For each impression, the time required to mix the material and complete a full-mouth (maxillary and mandibular arches) impression was recorded.

Immediately following the impression procedure, each participant was asked to complete the VAS survey described above, and return it before the end of the appointment. Each millimeter VAS score was measured to the nearest 0.5 millimeter, and medians and interquartile ranges were calculated for each response.

**STATISTICAL ANALYSES**

The reliability of the survey instrument was assessed using the data from the pilot study to measure intraclass correlation coefficients for each survey question.

Sample size calculations were completed prior to data collection. With a non-directional alpha risk of 0.05 and assuming a standard deviation of 24.25, a sample size of 50 subjects would allow a detection of a difference of ±14 mm on the VAS scale with a power of 0.823. To account for participant dropout and the possibility of using a non-
parametric data analysis, we added 20% to the $n$ of 50, yielding a sample size of 60 per group.

As the assumptions of parametric statistical analyses were not met, the data were analyzed using non-parametric tests. Medians and quartile ranges were calculated for subject gender, age, previous expression experience, impression time requirement, and each survey question. These data were analyzed statistically with the non-parametric Dwass, Steel, Critchlow-Flinger method multiple comparison analysis with a simultaneous P-value adjustment\textsuperscript{26}, and <.05 as the level for statistical significance. The data analysis for this paper was generated using [SAS/STAT] software (Version 9.4 of the SAS System for X64_7PRO platform. Copyright © 2002-2012 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA).

**RESULTS**

Analysis of data from the pilot study indicated that each of the seven survey questions was found to be reliable. Four of the questions had excellent reliability, and three had moderate-to-good reliability. Intraclass correlation coefficient values are listed in Table 2.

For the main data acquisition study, analysis of participant demographic information showed that the three subject groups had no significant differences in gender; however, there were statistical differences in the age of participants as well as their
previous impression experiences. Median ages by impression group and for all participants combined are listed in Table 1.

All survey questions as well as impression time were not normally distributed as indicated by the Shapiro-Wilk statistic (P<0.0001). The analyzed data from the main survey administration study including median, interquartile range, and P-value information are summarized in Table 3. According to the satisfaction questionnaire, subjects had significantly more comfort and less pain with the iTero scanner than the 3Shape scanner and alginate impressions. The iTero participants also had significantly less dry mouth related to the impression. There was a significant difference among subject’s time perception between the iTero and alginate impressions, but no significant differences among the iTero and 3Shape impressions or alginate and 3Shape impressions. Significant differences were also found in the assessment of technician skill and importance of new technology, with iTero participants rating the technicians with higher skill level, and believing that new technology was important in an orthodontic office. When asked if they would rather go to an orthodontist with digital or alginate impressions, the iTero and 3Shape participants preferred digital impressions, while the alginate participants had less preference toward digital impressions. Differences in the time required to complete each impression type were found, with the 3Shape digital impression requiring significantly more time than the iTero and alginate impressions.

DISCUSSION
This study was conducted to investigating patients’ perceptions and opinions regarding these scanners, as well as relative chairside time requirements for different impression methods. Limited studies evaluating the use and patient perception of intraoral scanners in the orthodontic field have also been completed, with differing results. Vasudavan et al found that 77% of patients preferred intraoral scans over alginate impressions. Grünheid et al found that 73.3% of patients preferred alginate impressions over intraoral scans. Burhardt et al found that young patients preferred digital impression techniques over alginate impressions. The studies listed above used scanners that required teeth to be coated with a layer of titanium dioxide powder. Generally, it has been found that powdering the dentition causes dryness and some discomfort to the patients. Burhardt’s study investigated the impact of the titanium dioxide powder and found that over 60-70% of subjects reported noticing the powder. The scanners used in the present study do not use titanium dioxide powder, and are widely used and compatible with a variety of labs and orthodontic companies.

The survey instrument developed and used in this study utilized a visual-analogue scale (VAS) to measure participants’ opinions, which allowed subjects to indicate their level of agreement without forcing them to choose a pre-determined response. Low values (0) indicate agreement, mid-range values (50) indicate neutrality, and high values (100) indicate disagreement. The seven questions included in the survey tested three areas of patient satisfaction: comfort, perceived time & technician skill, and novelty.

Questions 1-3 evaluated subjects’ comfort during the impression (Figure 4). When questioned about comfort, the iTero group had significantly lower scores than the
3Shape and alginate groups. The 3Shape group also had a lower median score than the alginate group, but this difference was not statistically significant. Similar results were found when questioned if the impression was painless, with the iTero group having significantly lower values than the other two groups. Subjects may have experienced less pain and discomfort with the iTero scanner due to the smaller size of the intraoral camera portion and less bulky scanner wand. A question regarding dry mouth was included due to other intraoral scanners requiring titanium dioxide powder and associated feelings of mouth dryness, but none of the subject groups indicated significant feelings of dry mouth.

The following two questions evaluated participants’ perception of time and technician skill (Figure 5). Question four evaluated the subjects’ opinion of time required for the impression; all three groups had low median values, indicating that all participants felt their impression was faster than they expected. The iTero group had a significantly lower value than the alginate group, but there were no other significant differences among groups. There was also not a direct correlation between subjects’ perceived time and the actual time required to obtain the impression among groups, as the 3Shape scans had the longest time requirement but the participants’ time perception was not different from other groups. Participants may have felt that the iTero impression was faster than expected because it was reported as the most comfortable, while having a more unpleasant experience may increase the perceived time. Because several different technicians were employed to make the impressions, a question concerning the skill level of the technician was included. All three groups had very low median values, suggesting that all participants believed their technician was highly skilled; however, the iTero group
had a significantly lower score than the 3Shape and alginate groups. This finding is interesting, as all technicians were very experienced in their impression method. The iTero group was enrolled from a private orthodontic practice whereas the 3Shape and alginate participants were enrolled from a university setting. This may impact the responses because patients of a private practice may be more familiar with their technicians.

The final two questions of the survey measured the subjects’ opinions of impressions regarding novelty (Figure 6). When asked about the importance of new technology in an orthodontic office, all subjects indicated that it was important, but the iTero group had a significantly lower median value. This may again be a result of the subjects’ demographics, as the iTero group were patients of a private practice while the 3Shape and alginate groups were from a university practice. Patients receiving care from a private orthodontic office may have higher expectations regarding equipment and technology used, while patients of a university practice may place less emphasis on those aspects. When participants were asked if they would rather receive treatment from an orthodontist who uses digital impressions rather than alginate, both digital groups indicated they would, in fact, prefer an orthodontist with digital models. However, the alginate group had a significantly higher median with a lack of preference. This is an interesting finding because all groups indicated that new technology was important to them, implying that all groups would prefer the newer technology of digital impressions over alginate impressions. While this notion holds true for the iTero and 3Shape groups, the alginate group was indifferent on the impression method used by their orthodontist.
Perhaps the subjects who had alginate impressions were more neutral in their preference because they are fond of their current orthodontist, regardless of his or her impression technique.

In comparing the chairside time required to complete each type of impression, the 3Shape digital impression required significantly more time than the other two impression groups (Figure 7). The alginate impressions had the shortest median time, followed by the iTero digital intraoral scan; these groups were not significantly different from one another. It should be noted that these measurements include only the time spent making the impression, and do not take into consideration the time required to disinfect and process any of the impressions. One possible explanation for the differences in impression time between the intraoral scanners is the age of the unit. The iTero element was released in the summer of 2015, while the 3Shape color scanner used was released in early 2014. Since this study was initiated, an updated version of the 3Shape scanner (3Shape TRIOS 3) became available to the market, and may be more competitive with the iTero regarding size of intraoral tip and scanning efficiency.

Our study did not have any age, race, ethnicity or gender exclusions for participants, with the purpose of obtaining a study sample which is representative of a true orthodontic population. Additionally, the subjects had varied prior impression experiences: some participants had never had any type of impression before, and some had previously undergone alginate and/or digital impressions. After data analysis, there were no significant differences found in gender between impression groups; however, the groups were not equally matched regarding age and previous impression experience. For
all groups, median ages were similar, but the alginate group was statistically significant for increased age. This finding could be significant in terms of the subjects’ responses, because age may impact the relative value of their priorities. Along with differences in subject age, previous impression experience was not equal among groups. Again, we cannot be sure if the patient’s previous exposure to impressions affects their responses to the questionnaires.

While the study revealed some significant differences in patient satisfaction regarding digital and alginate impressions, the limitations of this study should be recognized. As mentioned above, the lack of even distribution for age and previous impression experience among groups are confounding variables that could affect the subjects’ responses. Secondly, multiple technicians obtained the impressions. Personal experience with the technician could affect subjects’ opinions of the impression; however, it was necessary to utilize several technicians because we required operators with extensive experience in each impression method. Additionally, the research was conducted at different sites. This could bring about population differences regarding socioeconomic status and attitudes, which could potentially influence subjects’ responses. Finally, as with all research involving surveys and questionnaires, the inherent issue of response bias is present.

**CONCLUSIONS**

This study found that orthodontic patients are satisfied with and accept intraoral digital impressions. The digital 3Shape scanner required more chairside time than the
iTero and alginate impression methods. As intraoral scanning technology continues to advance with smaller cameras and faster acquisition times, patients may show increased preference for digital impressions. Research in related areas including the impact of patient age, previous impression experience, and rapport with operator is warranted, as well as doctor and technician satisfaction with different impression methods. When determining when to incorporate intraoral scanning into a practice or which scanner to invest in, practitioners should evaluate patient acceptance and efficiency as well as other factors such as accessibility, compatibility, and cost.
CHAPTER 4:

Results

Analysis of the 17 paired surveys from the pilot study indicated that each of the seven survey questions was found to be reliable. Four of the questions had excellent reliability, and three had moderate-to-good reliability. The survey instrument also demonstrated excellent inter-rater reliability. Intraclass correlation coefficient values are listed in Table 2.

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Table 2. Reliability of measures for survey instrument

The analyzed data from the main survey administration study including median, interquartile range, and P-value information are summarized in Table 3.
Table 3. Median values and interquartile ranges (Q3-Q1) for survey responses and time requirements for each impression group.

For the main data acquisition study, analysis of participant demographic information showed that the three subject groups had no significant differences in gender; however, there were statistical differences in the age of participants as well as their previous impression experiences.

According to the satisfaction questionnaire, subjects had significantly more comfort and less pain with the iTero scanner than the 3Shape scanner and alginate impressions. The iTero participants also had significantly less dry mouth related to the
impression. There was a significant difference among subject’s time perception between the iTero and alginate impressions, but no significant differences among the iTero and 3Shape impressions or alginate and 3Shape impressions. Significant differences were also found in the assessment of technician skill and importance of new technology, with iTero participants rating the technicians with higher skill level, and believing that new technology was important in an orthodontic office. When asked if they would rather go to an orthodontist with digital or alginate impressions, the iTero and 3Shape participants preferred digital impressions, while the alginate participants had less preference toward digital impressions.

Differences in the time required to complete each impression type were found, with the 3Shape digital impression requiring significantly more time than the iTero and alginate impressions.
CHAPTER 5:

Discussion and Conclusions

Continual advances in technology are being made in the orthodontic field to improve the accuracy and efficiency of diagnosis and treatment of patients. Digital intraoral scanners are a relatively recent development in orthodontics, and have quickly made their way into many practices. Investigating patients’ perceptions and opinions regarding these scanners can help orthodontic practitioners decide if chairside intraoral scanners are worth the investment, as well as which scanners will work best in their practice. Additionally, data from patients’ perspectives may be valuable to product companies and could influence what changes are made in new equipment.

Several previous studies have established the accuracy of intraoral digital impressions compared with that of conventional alginate impressions\(^7\)\(^{-11}\). Additional studies have looked at patient acceptance and preference between digital and alginate impression types. Digital impressions used for prosthodontic and restorative means have been studied, and recent data suggest that patients prefer digital impressions to conventional polyether techniques\(^17\)\(^{-19}\). Limited studies evaluating the use and patient perception of intraoral scanners in the orthodontic field have also been completed, with differing results\(^10\),\(^17\),\(^27\). Vasudavan et al found that 77% of patients (30 subjects) preferred intraoral scans over alginate impressions. Grünheid et al found that 73.3% of
patients (15 subjects, ages 12-52) preferred alginate impressions over intraoral scans. They also found that alginate impressions are faster regarding chairside time, but after including processing time, intraoral scans have a faster total time requirement. Burhardt et al found that young patients (38 subjects, ages 10-17) preferred digital impression techniques over alginate impressions, and again that alginate impressions required less chairside time. All of the studies reviewed above completed intraoral scans with two types of scanners, the Lava COS and the Cerec Omnicam; both of these types of intraoral scanners required teeth to be coated with a layer of titanium dioxide powder. Generally, it has been found that powdering the dentition causes dryness and some discomfort to the patients. Burhardt’s study investigated the impact of the titanium dioxide powder and found that when scanned with the Lava COS and CEREC Omnicam scanners, 64% and 74% of subjects, respectively, noticed the powder. After investigating the intraoral scanners available and those most frequently used by orthodontists, we chose to include the iTero and 3Shape scanners in our study. These intraoral scanners do not use titanium dioxide powder, and are widely used and compatible with a variety of labs and orthodontic companies.

The survey instrument developed and used in this study utilized a visual-analogue scale (VAS) to measure participants’ opinions. By using a VAS, we allowed subjects to indicate their level of agreement without forcing them to choose a pre-determined response. The left end of the scale was anchored with “agree,” and the right end with “disagree.” The individual responses were measured by millimeter from left to right; therefore, low values (0) indicate agreement, mid-range values (50) indicate neutrality.
and high values (100) indicate disagreement. The seven questions included in the survey tested three areas of patient satisfaction: comfort, perceived time & technician skill, and novelty.

Questions 1-3 evaluated subjects’ comfort during the impression, and these results are summarized in Figure 4. When asked if having impressions made is comfortable, the iTero group had significantly lower scores (indicating higher agreement) than the 3Shape and alginate groups. The 3Shape group also had a lower median score than the alginate group, but this difference was not statistically significant. Similar results were found when questioned if the impression was painless, with the iTero group having significantly lower values than the 3Shape and alginate groups. Subjects may have experienced less pain and discomfort with the iTero scanner due to the smaller size of the intraoral camera portion and less bulky scanner wand. A question regarding dry mouth was included due to other intraoral scanners requiring titanium dioxide powder and associated feelings of mouth dryness, but none of the subject groups indicated significant feelings of dry mouth. The iTero had a significantly higher median value than the other two groups, indicating that they did not experience a dry mouth; the 3Shape group had the lowest median score, but it was not significantly different from the alginate group.

The following two questions evaluated participants’ perception of time and technician skill, and the results are shown in Figure 5. Question four evaluated the subjects’ opinion of time required to complete the impression; all three impression groups had low median values (below 20), indicating that all participants felt their impression was faster than they expected. The iTero group had a significantly lower value than the
alginate group, but there were no other significant differences among groups. There was also not a direct correlation between subjects’ perceived time and the actual time required to obtain the impression among groups, as the 3Shape scans had the longest time requirement but the participants’ time perception was not different from other groups. Participants may have felt that the iTero impression was faster than expected because it was not painful or uncomfortable, while having a more unpleasant experience may increase the perceived time. Because several different technicians were employed to make the impressions, a question concerning the skill level of the technician was included. All three groups had very low median values (below 10), suggesting that all participants believed their technician was highly skilled; however, the iTero group had a significantly lower score than the 3Shape and alginate groups. This finding is interesting, as all technicians were very experienced in their impression method. The iTero group was enrolled from a private orthodontic practice whereas the 3Shape and alginate participants were enrolled from a university setting. This may impact the responses because patients of a private practice may be more familiar with their technicians and could believe they have more experience than those employed in a university practice.

The final two questions of the survey measured the subjects’ opinions of impressions regarding the novelty of digital technology, and overall preference between digital and conventional impression techniques. The results of these questions are displayed in Figure 6. When asked about the importance of new technology in an orthodontic office, all subjects indicated that it was important, but the iTero group had a significantly lower median value. This may again be a result of the subjects’
demographics, as the iTero group were patients of a private practice while the 3Shape and alginate groups were from a university practice. Patients receiving care from a private orthodontic office may have higher expectations regarding equipment and technology used, while patients of a university practice may place less emphasis on those aspects. When participants were asked if they would rather receive treatment from an orthodontist who uses digital impressions rather than alginate, both digital groups indicated they would, in fact, prefer an orthodontist with digital models. However, the alginate group had a significantly higher median score close to 50mm, indicating a lack of clear preference. This is an interesting finding because all groups indicated that new technology was important to them, implying that all groups would prefer the newer technology of digital impressions over alginate impressions. While this notion holds true for the iTero and 3Shape groups, the alginate group was indifferent on the impression method used by their orthodontist. Perhaps the subjects who had alginate impressions were more neutral in their preference because they are fond of their current orthodontist, regardless of his or her impression technique.

In comparing the chairside time required to complete each type of impression, the 3Shape digital impression required significantly more time than the other two impression groups. The alginate impressions had the shortest median time, followed by the iTero digital intraoral scan; these groups were not significantly different from one another. The median time requirement for each impression method are illustrated in Figure 7. It should be noted that these measurements include only the time spent making the impression, and do not take into consideration the time required to disinfect and process any of the
impressions. One possible explanation for the differences in impression time between the intraoral scanners is the age of the unit. The iTero element was released in the summer of 2015, while the 3Shape color scanner used was released in early 2014. Since this study was initiated, an updated version of the 3Shape scanner (3Shape TRIOS 3) became available to the market, and may be more competitive with the iTero regarding size of intraoral tip and scanning efficiency. While the increased time required for the 3Shape scanner in this study was statistically significant, the difference amounted to only one minute and 40 seconds. When looking at the efficiency of different impression methods, each individual practitioner should balance the value of chairside time with the value of other, often intangible, factors to make the right decision for their practice. Additionally, all of the technicians who obtained the impressions for this study had experience with the impression method they used. When acquiring any new office technology, there is a so-called “learning curve,” in which the new approach will be less efficient than the previous system.
Figure 4. Data results from questions 1-3 regarding subjects' perceptions of comfort with varying impression methods

Figure 5. Data results from questions 4 and 5 regarding subjects' perceptions of time & technician skill with varying impression methods

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Figure 6. Data results from questions 6 and 7 regarding subjects’ perceptions of *novelty and preference* of varying impression methods

Figure 7. Median time required for each impression method
Our study did not have any age, race, ethnicity or gender exclusions for participants, with the purpose of obtaining a study sample which is representative of a true orthodontic population. Additionally, the subjects had varied prior impression experiences: some participants had never had any type of impression before, and some had previously undergone alginate and/or digital impressions. After data analysis, there were no significant differences found in gender between impression groups; however, the groups were not equally matched regarding age and previous impression experience. For all groups, median ages were similar (iTero: 14 yrs, 3Shape: 15 yrs, alginate: 17 yrs), but the alginate group was statistically significant for age difference. This finding could be significant in terms of the subjects’ responses, because age may impact the relative value of their priorities. For instance, children may be more prone to gagging, and also less concerned with the time required for impressions; therefore, they may prefer digital impressions. Conversely, adults may place more emphasis on the efficiency of impression rather than the sensation. Along with differences in subject age, previous impression experience was not equal among groups. Again, we cannot be sure if the patient’s previous exposure to impressions affects their responses to the questionnaires. In some situations, a former adverse experience could cause the subject to view any impression negatively, with this view reflected in their answers to survey questions. Likewise, a patient who has previously had a positive, or unremarkable, experience may be more optimistic when completing the questionnaire.

While the study revealed some significant differences in patient satisfaction regarding digital and alginate impressions, the limitations of this study should be
recognized. Firstly, as mentioned above, the lack of even distribution for age and previous impression experience among groups are confounding variables that could affect the subjects’ responses. Secondly, multiple technicians obtained the impressions. The personal rapport with the technician could affect subjects’ opinions of the whole impression experience, rather than the impression itself. However, it was necessary to utilize several technicians because each impression method is technique sensitive, and we required expert operators who had extensive experience with each method. Additionally, the research was conducted at different sites. It would be unusual for one orthodontic practice to have each type of intraoral scanner, and to employ them both equally along with alginate impressions. Consequently, participants were recruited from two separate practices: the graduate resident practice at the Ohio State University College of Dentistry, and a private orthodontic practice in the same area. This could bring about population differences regarding socioeconomic status and attitudes, which could potentially influence subjects’ responses. Finally, as with all research involving surveys and questionnaires, the inherent issue of response bias is present.

Conclusions

This study found that orthodontic patients are satisfied with and accept intraoral digital impressions. The digital 3Shape scanner required more chairside time than the iTero and alginate impression methods. As intraoral scanning technology continues to advance with smaller cameras and faster acquisition times, patients may show increased preference for digital impressions. Research in related areas including the impact of
patient age, previous impression experience, and rapport with operator is warranted, as well as doctor and technician satisfaction with different impression methods. When determining when to incorporate intraoral scanning into a practice or which scanner to invest in, practitioners should evaluate patient acceptance and efficiency as well as other factors such as accessibility, compatibility, and cost.
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