HUMAN PERCEPTION OF DENTAL DISCREPANCY

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ABSTRACT

Hugh G. Murphy: Human Perception of Dental Discrepancy
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The purpose of this research study is to determine the range of mesiodistal width discrepancies for a single missing maxillary incisor, in which digital restoration of the missing tooth produces: (1) no perceivable discrepancy, or (2) a result that would be considered unacceptable by patients and dental professionals respectively. An electronic survey was administered in which participants were asked to look at a series of carefully modified digital models of a maxillary arch, and then assess differences in width of two teeth and rate the overall appearance of the teeth. Results indicate a range of actual mesiodistal width discrepancy for a central incisor (-1.5mm to +1.0mm) and lateral incisor (-1.0mm to +0.5mm) for which a digital wax-up was considered esthetically acceptable by at least 95% of patients.

To my family:

Thank you for making this possible, life beautiful and my day to day more enjoyable.

To my mentors:

Thank you for guiding me through the hard lessons that have taught me how to learn and build upon my practice of improving the lives of others.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SECTION 1

LITERATURE REVIEW

INTRODUCTION

There is an abundance of evidence available in the literature going as far back as the 1890s with GV Black's publication of: *Descriptive Anatomy of Human Teeth,* which supports the commonly held consensus that teeth tend to fall within a characteristic range of definable dimensions with notable averages and relative proportionality.[1] It seems logical that there would also be similar trends in what humans perceive to be esthetic when it comes to teeth and an individual's smile. Historically, the published literature on dental esthetics has focused on trying to identify ideals and principles governing tooth size, proportion, morphology, orientation, and their relation to the lips, gingival tissues, face and smile. The paradigms that emerged and evolved from these efforts were intended to make the science and clinical practice in dental esthetics more quantifiable and predictable.

ESTHETIC PARADIGMS

The Golden Proportion

One of the earliest paradigms of dental esthetics was the "golden proportion". The golden proportion dictates that for two related objects to appear natural and harmonious, the larger to the smaller should form a ratio of 1.618 to 1, where the smaller object is about 62% of the larger.[2] It is a concept derived from classical mathematics. It can be derived from the succeeding terms of the Fibonacci mathematical progression in which each number is the sum of the 2 immediately preceding it: 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144… which converges to the golden proportion 1.618:1.[3]

As applied to dental esthetics, the golden proportion postulates that a 62% progressive reduction in the perceived mesiodistal widths of the maxillary anterior teeth as viewed from the frontal perspective is considered to be esthetically pleasing.[4] One of the first to describe the golden proportion and its importance in restorative dentistry was Lombardi[5], while others, including Levin[6], Brisman[7], Qualtrough and Burke[8], have reinforced its application to anterior dental esthetics. These attempts at defining ideal dental esthetics, however, eventually led researchers to ask the question what can be observed in naturally esthetic dentitions and how can we quantify an esthetic smile.

Preston measured the perceived widths of the maxillary central and lateral incisors on 58 imaged casts and found that the golden proportion was not observed; instead, he reported a mean perceived central incisor to lateral incisor width ratio of 1.51:1.[9]

Gillen et al. conducted a study on 54 dental casts to determine the average dimensions of the maxillary anterior teeth and assess their inter/intra tooth dimensional relationships, and found that the golden proportion did not correlate with any of the calculated ratios.[10] It was concluded that the golden proportion is not valid when applied to actual tooth proportions; rather, it is only relevant to perceived tooth proportions evaluated from the frontal perspective.

This observation was later investigated by Hasanreisoglu et al. who compared the mesiodistal width of the maxillary anterior teeth of 100 dental students measured on casts to the perceived widths measured on corresponding images, and found that the actual and perceived dimensions of the anterior teeth when viewed from the facial differed because of the curvature of the arch and angulation of the teeth in relation to the frontal plane of the photograph.[11] Thus, there is an important distinction to be made between perceived and actual proportions of teeth when considering dental esthetics. The issue here is that perception is a subjective measure, and should therefore be considered an important factor when dealing with dental esthetics.

Bukhary et al. evaluated the influence of varying the dimensions of the maxillary lateral incisor on the perception of smile esthetics. A photograph of a female smile was digitally altered in 5% increments to produce maxillary lateral incisor widths ranging from 52% to 77% of the width of the adjacent central incisor. The images were ranked from “most attractive” to “least attractive” by 41 hypodontia patients, 46 nonhypodontia “controls,” and 30 dentists. The images showing 67% lateral incisor to central incisor width proportions were considered to be the most attractive, and the golden proportion was not preferred by the majority of evaluators.[12]

Similarly, another study by de Castro et al. that assessed the prevalence of the golden proportion in subjects considered to possess an agreeable smile found only 7.1% of these smiles exhibiting the golden proportion.[13]

Currently, based on the vast majority of evidence available, it is clear that the golden proportion is not generally evident in natural dentitions, nor is it considered esthetically pleasing by dentists or laypeople, and hence is not suitable for clinical application in restorative dentistry.

The Recurring Esthetic Dental Proportion

The recurring esthetic dental (RED) proportion was a concept proposed by Ward which postulates that when viewed from the front each successive tooth depreciates by the same proportion relative to the tooth mesial to it, and that although the actual proportion may vary (e.g., 70%, 75%, 80%, etc.) because of factors like differences in tooth height, the selected RED proportion must be applied consistently to the specific smile of an individual.[14]

Rosenstiel et al used computer-manipulated images of the six maxillary anterior teeth, which were assigned to five groups based on differing tooth height (very short to very tall), and for each group, the mesiodistal tooth proportion was manipulated to reflect a successive decrement of 62% (or “golden proportion”), 70%, 80%, and “normal” or unaltered, relative to the tooth mesial to it. The four images for each group were randomly evaluated by dentists who were then asked to rank them from best to worst. The findings were (1) Dentists preferred the 80% proportion when viewing short or very short teeth and the golden proportion when viewing very tall teeth; (2) the golden proportion was considered the worst for normal height or shorter teeth; and (3) the 80% proportion the worst for tall or very tall teeth. There was no consensus on the best proportion for normal height or tall teeth, and their choices could not be predicted based on gender, specialist training, experience, or patient load.[15] A confounding factor in this study design was that it was difficult to determine whether the evaluation of the manipulated images were indicative of the effect of change in intertooth mesiodistal proportion or the participants were influenced by the inherent changes in the intratooth width to height ratios.[16]

Another study by Ward surveyed dentists to determine their preferences of imaged smiles exhibiting different anterior tooth width proportions and the primary proportion influencing their decision. Of the 301 dentists surveyed 57% preferred smiles with the 70% RED proportion when evaluating teeth of normal height, and 62% of dentists cited the overall balance as the primary factor affecting their selection, while 23% made their selection based on the size of the maxillary central incisors.[17]

Ker and colleagues administered an electronic survey to 243 laypeople in Boston (n = 78); Columbus, Ohio (n = 81); and Seattle (n = 84). The survey employed an interactive digital slider bar to produce a visually continuous scale of images such that participants could move the slider bar to select what they considered ideal as well as the range of acceptability for each smile characteristic presented. The evaluators found the ideal lateral incisor mesiodistal crown width to be 72% the mesiodistal width of the central incisor, with a wide range of acceptability from 53% to 76% the width of the maxillary central incisor.[18]

Crown Width to Length Ratios

The width to length (or width to height) ratios of individual teeth, but especially the maxillary central incisors, is a very important factor that can influence the balance and esthetics of a smile. Sterrett et al evaluated crown height, width, and the width to height ratios of maxillary anterior teeth in 71 subjects and reported a mean width to height ratio of 0.81. Sterrett also found within both genders there is a positive correlation between tooth group width/length ratios, however no significant correlation was found between any of the tooth dimensions or ratios and subject height.[19]

Magne et al used standardized digital images of 146 extracted human maxillary anterior teeth from white subjects (44 central incisors, 41 lateral incisors, 38 canines, 23 first premolars) to measure the widest mesiodistal portion of the crown and the longest inciso-cervical distance (in millimeters), and then calculate the width to length (or width to height) ratio as a percentage for each tooth. The important difference in this study was that the length (or height) of the crown was assessed from cementoenamel junction (CEJ) as opposed to the free gingival margin of the clinical crown as was measured in earlier studies by Sterrett et al.[20 21] The results showed that incisal wear had no influence on the average width for each tooth group. The average widths of unworn and worn central incisors were 9.10mm and 9.24mm, unworn and worn lateral incisors were 7.07mm and 7.38mm, and unworn and worn canines were 7.90mm to 8.06mm, respectively. First premolars had an average width of 7.84mm. The length was naturally influenced by incisal wear, with worn teeth being shorter than unworn teeth, except for lateral incisors. The average lengths of unworn and worn central incisors were 11.69mm and 10.67mm, unworn and worn lateral incisors were 9.55mm and 9.34mm, and unworn and worn canines were 10.83mm and 9.90mm, respectively. First premolars had an average width of 9.33mm. Width to length ratios also showed significant differences between worn and unworn tooth groups, with unworn central incisors being (78%), unworn lateral incisors (73%) and unworn canines also (73%), as compared to worn central incisors (87%), worn lateral incisors (79%), and worn canines (81%). Width to length ratios for premolars were (84%).[22]

A study by Wolfart et al evaluated smiling images that were digitally altered to reflect varying width to height ratios of the maxillary central incisors while keeping the proportions between the widths of the central to lateral and lateral to canine constant. The images were evaluated by 179 laypersons, 24 dentists, and 24 medical students, who ranked each photo set for attractiveness on a visual analogue scale. The width to height ratios for central incisors determined most attractive by laypersons (medical students and patients) ranged from 75–85%, while dentists preferred ratios of 75–80%. The width to width proportion of the central incisors to the lateral incisors considered most attractive by laypersons fell within a wide range of 50–74%, while the dentists preferred a more narrow range of 56–68%. For the majority of responses, no significant differences between laypersons and dentists were found, however significant differences were noted between groups only for the extreme proportional variations.[23]

A study by Chu focused on determining the range and mean distribution frequency of individual tooth width in the maxillary anterior dentition. The widths of maxillary incisors and canines were evaluated on 54 diagnostic casts made from 36 female and 18 male patients. Results showed that lateral incisors, and canines varied in range from 7 mm to 10 mm, 5.5 mm to 8 mm, and 6.5 mm to 9 mm, respectively. Individual tooth width in millimeters among the 54 patients ranged in size from a minimum of 2.5 mm to a maximum of 3 mm, with the central incisors exhibiting the greatest range at 3 mm. Analysis of the data revealed that only 36% and 40% of the total population exhibited the mean tooth width of 8.5 mm for central incisors and 7.5 mm for canines, respectively. For the lateral incisors, 26% of the population exhibited a mean tooth width of 6.5 mm. As a group, a central incisor width of 8.5 mm, a lateral incisor width of 6.5 mm, and a canine width of 7.5 mm only occurred in 34% of the population; however, 82% of the patients fell within ±0.5 mm of the mean values. The data therefore demonstrated a "bell curve" or normal distribution.[24]

Vertical Position of the Maxillary Lateral Incisor

In an esthetic smile, it has been suggested that the maxillary central incisors and canines be positioned approximately in level with each other, with the incisal edge of the lateral incisors positioned approximately 1 to 1.5mm superior.[25] However, the esthetic impact of variations in the vertical position of the maxillary lateral incisor remains unclear. A study by King et al evaluated the preferences for vertical maxillary lateral incisor position among orthodontists, general dentists, and laypeople. The judges in this study preferred the maxillary lateral incisors to be set about 0.5mm above the incisal plane and not level with the central incisors and canine.[26]

The Apparent Contact Dimension

The apparent contact dimension (ACD) is an important indicator of maxillary anterior vertical tooth proportions. Previously known as the "connector zone", ACD is defined as the area where teeth appear to contact each other when viewed from the facial aspect at 90 degrees to the interproximal area.[27] The ACD of an esthetic smile has been purported to exhibit a proportional relationship relative to the central incisors which is commonly referred to as the 50:40:30 rule.[28] The 50:40:30 rule describes the ideal ACD ratio between central incisors as 50% of the central incisor tooth height; the ideal ratio for central and lateral incisor ACD is 40% of the central incisor height; and the ideal ratio for lateral incisor and canine ACD is 30% of the central incisor height.[29] Furthermore, incisal embrasures are smallest between central incisors and grow larger as they progress posteriorly in the dentition.[30] [31]

The esthetic import of variations in ACD proportions, as perceived by laypeople, is a very important factor to consider during treatment planning any periodontal surgery, orthodontic finishing, or prosthodontic restoration/replacement in the maxillary anterior region. The literature has reported variation in perceptions of esthetics with regard to different ACD proportions.[32 33 34 35] Nevertheless, it remains clear that ACD is an important factor to consider when treatment planning the rehabilitation of an individual's anterior dentition, as interproximal areas dominated by tooth contact may not be perceived by the patient to be as esthetic as one where tooth contact and papilla exhibit more equitable proportions.[36 37 38]

PERCEPTION OF ALTERED DENTAL ESTHETICS

Tooth-size discrepancies are common, especially in orthodontic populations, and fairly evenly distributed among gender, ethnicity, and various malocclusion categories.[39 40] Discrepancies in the maxillary anterior dentition have a plethora of different etiologies for which there can be numerous treatment options. Be that as it may, one universal truth that applies to any esthetic treatment is that success is ultimately measured by the patient and requires their acceptance. For this reason, it is tremendously important for dental professionals to understand general principles of their patients' perception of altered dental esthetics.

Kokich et al studied the perception of laypersons, dentists and orthodontists to altered dental esthetics as defined by minor variations in anterior tooth size and alignment and their relation to the surrounding soft tissues.[41] Smiling photographs were digitally altered with one of eight common anterior esthetic discrepancies in varying degrees of deviation, including variations in crown length, crown width, incisor crown angulation, midline, open gingival embrasure, gingival margin, incisal plane, and gingiva-to-lip distance. With respect to changes in crown width, it was determined that since the most common variation in crown width affects the size of the lateral incisors, the 1.0mm incremental alterations of crown width of the maxillary lateral incisors were made in a symmetrical fashion while the marginal gingiva was kept at the same level. A survey was created in which these 40 images were randomized with 4 images per page such that different variables were presented on each page of the questionnaire, and copies of the original questionnaire were randomly arranged in 10 different ways. Participants rated images according to dental attractiveness using a 50mm visual analogue scale, and it is important to note that each rater was given as little information about the study as possible. A total of 300 questionnaires were distributed to three groups: (1) orthodontists and (2) general dentists selected from a list of graduates of the University of Washington School of Dentistry, and (3) laypersons. The response rate was high, with 88.2% for orthodontists, 60.6% for lay people, and 51.8% for general dentists.[42]

The results showed that orthodontists, general dentists, and laypersons detect specific dental esthetic discrepancies at varying threshold levels of deviation.[43] A 3.0mm symmetrical narrowing in maxillary lateral incisor crown width were required by orthodontists and general dentists to be rated significantly less esthetic, while lay people were unable to detect a symmetrical lateral incisor narrowing until it reached 4.0mm. Open gingival embrasure became detectable by orthodontists at 2.0mm, and general dentists and lay people at 3.0mm. A maxillary midline deviation of 4.0 mm was necessary before orthodontists rated it significantly less esthetic, while general dentists and laypersons did not detect midline deviation.[44] The differing levels of detectability demonstrate that minor variations in specific dental esthetic discrepancies may not be an important concern to most patients, and that it is up to the dental professional to educate the patient and allow them to make their own determination as to the overall esthetic significance of each discrepancy.[45]

Kokich et al then conducted a very similar study evaluating the perception of laypersons and dental professionals to asymmetric alterations of dental esthetics.[46] Seven images of women's smiles were altered with a software-imaging program. These alterations, selected based on frequency and clinical significance to the smile, included variations in crown length; crown width, without altered crown length and with proportionally altered crown length; midline diastema; papillary height, with unilateral asymmetry and bilateral symmetry; and gingiva-to-lip distance. The altered images were rated by groups of general dentists, orthodontists, and laypersons using a visual analog scale. Statistical analysis of the responses resulted in the establishment of threshold levels of attractiveness for each group.[47]

The results showed that asymmetric alterations make teeth more unattractive to not only dental professionals but also to laypersons. It also showed that orthodontists were more critical than dentists and laypeople when evaluating asymmetric crown length discrepancies. All 3 groups could identify a unilateral crown width discrepancy of 2.0 mm.[48] All 3 groups detected a unilateral discrepancy involving 1 lateral incisor earlier than the same discrepancy involving both lateral incisors.[49] [50] When crown width was altered with a proportional change in length, the results differed from those seen with isolated crown width discrepancies. A mesiodistal dimension 3.0mm narrower than the ideal lateral incisor crown width was required before it was rated significantly less attractive by orthodontists and dentists, and a 4.0mm proportional narrowing of mesiodistal width was necessary for laypersons to rate it noticeably less attractive.[51] The same held true for similar lateral incisor alterations made bilaterally evaluated in earlier studies.[52 53] A small midline diastema was not rated as unattractive by any group. Unilateral reduction of papillary height was generally rated less attractive than bilateral alteration.[54] Dental Professionals rated a unilateral papillary height discrepancy of 0.5 to 1.0mm unattractive. In contrast, the layperson group did not perceive a significant difference in attractiveness even when evaluating the maximum 2.0mm deviation in papillary height. Orthodontists and laypersons rated a 3.0mm distance from gingiva to lip as unattractive. It was therefore concluded that asymmetric esthetic discrepancies are more perceptible than symmetric discrepancies and careful treatment planning and discussion should occur before the initiation of any esthetic treatment.[55]

Alsulaimani et al conducted a study to determine whether alteration of the maxillary central and lateral incisors' length and width would affect perceived smile esthetics as well as validate the most esthetic length and width, respectively, for the central and lateral incisors.[56] Just as was done in previous studies, photographic manipulation used to alter images of a selected smile. In this study, two sets of 4 photographs were produced, with each set photographs showing the altered width of the lateral incisor and length of the central incisor. The images were then assessed by a total of 307 participants (115 dentists, 68 orthodontists and 124 laypeople). After a brief explanation, the participants were asked to rate each image. The photographs were shuffled and presented individually. Participants were allowed to view each photograph for as long as they found necessary. The participants used a numeric rating scale, where score 0 is the least esthetic while score 5 is the most esthetic. Alteration in the incisors' proportion affected the relative smile attractiveness for laypeople, dentists and orthodontists; dentists and orthodontists did not accept lateral width reduction of more than 0.5 mm ($P<0.01$), which suggests that the lateral to central incisor width ratio ranges from 54% to 62%. However, laypeople did not accept lateral width reduction of more than 1 mm ($P<0.01$), widening the range to be from 48% to 62%. All groups had zero tolerance for changes in central crown length ($P<0.01$). The main conclusions from this study were that changes in central incisor length are readily perceived by both dental professionals and laypersons while dental professionals are more sensitive to perceiving changes in width of the incisors.[57]

Machado et al studied the perception of smile esthetics among orthodontists and laypeople with respect to asymmetries on the maxillary incisor edges in a frontal smile analysis. Photos of healthy esthetic smiles were digitally altered to create tooth wear on the maxillary left central and lateral incisors in 0.5-mm increments. The final images were randomly assembled into a photo album that was given to 120 judges (60 orthodontists and 60 laypersons). Each rater was asked to evaluate the attractiveness of the images with visual analog scales. Results showed that the most attractive smiles in both types of smiles were those without asymmetries and the 0.5- mm wear in the lateral incisor. Tooth wear was considered unattractive by both groups and the more wear the more unattractive the smile. Furthermore, tooth wear in the central incisor was considered more unattractive than in the lateral incisor. For both group of raters, 0.5 mm of wear in the central incisor was considered unattractive, whereas the thresholds for lateral incisor discrepancies were 0.5mm for orthodontists and 1.0mm for laypersons. These results upheld those from previous studies that symmetry between the maxillary central incisors is a paramount goal for successful esthetic treatments.[58]

Ma et al conducted a study that determined how sensitive dental specialists and laypeople are to maxillary incisor crowding when viewed from the front. Computer technology was used to create a series of photographs of a woman's smile viewed from the front that was digitally merged with a typodont. The teeth in the typodont were arranged with varying degrees of maxillary incisor crowding classified according to Little's irregularity index (LII). These images were ranked on a scale from 1 to 5, with 1 representing the worst incisor irregularity and 5 the best incisor alignment, by 4 groups of people: orthodontists, general dentists, laypeople with experience of orthodontic treatment, and laypeople with no history of orthodontic treatment. A score of 3 or less was considered to indicate a level of incisor crowding that was unacceptable. The orthodontists and the general dentists noted misalignment of 1 central incisor when the LII reached 1.5 mm, whereas the laypeople with or without experience of orthodontic treatment were sensitive to 2.0 mm of crowding. When the misalignment involved both central incisors the orthodontists were sensitive to 2.0mm of LII, whereas the general dentists and the laypeople with experience of orthodontic treatment became sensitive at 3.0mm of LII, and the laypeople with no history of orthodontic treatment were sensitive at 4.0mm of LII. When the misalignment involved both lateral incisors, the orthodontists noticed an LII of 3.0 mm, general dentists LII of 4.0 mm, whereas both groups of laypeople ignored it. When the crowding of all maxillary incisors reached an LII of 4 mm, both orthodontists and general dentists noticed the crowding, while laypeople noticed crowding at an LII of 6.0 mm. The results indicated (1) that orthodontists are more critical than other groups when evaluating misalignment of maxillary incisors; (2) the alignment of the central incisors has a greater influence on smile esthetics than that of the lateral incisors; and (3) people are more sensitive to the misalignment of a single tooth than they are to the same level of crowding distributed over multiple teeth.[59]

Hayes et al reported that 10 degrees of axial midline angulation was considered esthetically unacceptable by 68% of orthodontists and 41% of laypeople.[60]

Lee et al conducted a study using 3-dimensional scans and software to compare real tooth sizes and perceived tooth sizes between different genders and populations and analyze the effects of 3-dimensional tooth position and alignment. Dental stone casts were made for 139 subjects (50 males and 44 females from Korea and 46 females from Japan). Using 3-dimensional scanning and reconstructions, virtual models were constructed and the widths, lengths and rotations of maxillary anterior teeth were measured, and arch form parameters were measured orthographically. A regression model was created to interpret the values of 2-dimensional perceived widths with 3-dimensional measurements and other parameters. Results showed differences in the average mesiodistal perceived and actual dimensions of the maxillary central incisors between Japanese and Korean females, as well as differences in the ratios of lateral to central incisors and canine to lateral incisors in the perceived 2-dimensional measurements. There were no differences in individual tooth rotations between groups and the calculated values of the regression model decreased from the central incisors to the canine. It was concluded that several differences were found between Japanese and Korean females. Also the regression model that included actual dimensions, rotations and arch form parameters as independent factors was not sufficient to explain the perceived widths of the lateral incisors and canines in any of the groups in this study.[61]

This indicates that actual measurements of teeth width, rotation and the inter-canine width are not sufficient to explain perceived width, especially in the canine site, and there are other factors such as the labial convexity of individual teeth which can influence the perceived width of the anterior teeth.[62]

Zhang et al conducted a study in which the labial groove-textures of 158 upper central incisors from 79 volunteers, aged 19 to 24 years, were defined and explored to imitate the elaborate groove-textures for aesthetic restorations. The length, width, depth, combination and distribution of the horizontal and vertical grooves on the labial surface were investigated by an optical measurement method, based on the Shadow Moire´ technology and Temporal Fourier analysis. Results showed that vertical grooves were confirmed to be present in 94% of the samples and horizontal grooves in 77%. Perfect symmetry was shown in the vertical grooves of the same tooth, as well as in the homonymous teeth. The majority of horizontal grooves were distributed in the proximity of the cervical fourth and the middle of the crown. Based on the combination and distribution of the grooves, eight basic labial groove texture types of maxillary central incisors were classified. Any dental restoration of anterior teeth should pay close attention to these vertical and horizontal grooves in addition to other contours if it is to mimic the natural morphology of the patient's teeth.[63]

Currently, 3-dimensional software and virtual models display a high degree of accuracy and precision and can be used for many applications outside of CAD/CAM fabrication of dental restorations. Brandão et al demonstrated that Bolton analysis performed utilizing 3Shape® R-700T scanner (Copenhagen, Denmark) and digital measures obtained by Ortho Analyzer software on virtual models is as reliable as measurements obtained from dental casts with satisfactory agreement.[64]

With such exciting developments of CAD/CAM technologies in dentistry, it can be easy to assume that a digital diagnostic wax up will be easier or more successful. In a study by Abduo on the difference between digital and conventional analogue wax-ups, it was reported that although digital wax-up had slightly improved the single tooth symmetry, the conventional wax-up had a minimal impact on single tooth symmetry; and the anterior segment morphological asymmetry was minimally affected by both digital and conventional wax-ups.[65] It was noted however, that this observation was based on digital image registration which quantifies the similarity between two surfaces and does not determine the true aesthetic value. It was added that future research should be aimed at measuring the patient's satisfaction to confirm the aesthetic benefit of the digital workflow.

One potential advantage of the digital wax-up should be that it is cost effective and time efficient and transferrable to the clinic. Physical models of the digital wax-up can only be produced by 3D printing or milling[66], which will introduce actual discrepancies. For instance, dimensional error of models produced by 3D printing can be greater than 100 μm[67]. Similarly, Cho et al had found that dental casts produced by conventional methods exhibited better overall accuracy than digitally produced casts.[68] For these reasons, digital work flow has tremendous advantages and applications in dentistry, but like any tool, the user must have a firm grasp of its limitations in order to both avoid unsuccessful outcomes as well as improve the development of the technology in the future.

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SECTION 2

MANUSCRIPT

INTRODUCTION

There is an abundance of evidence available in the literature going as far back as the 1890s with GV Black's publication of: *Descriptive Anatomy of Human Teeth,* which supports the commonly held consensus that teeth tend to fall within a characteristic range of definable dimensions with notable averages and relative proportionality.[69] It seems logical that there would also be similar trends in what humans perceive to be esthetic when it comes to teeth and an individual's smile. Historically, the published literature on dental esthetics has focused on trying to identify ideals and principles governing tooth size, proportion, morphology, orientation, and their relation to the lips, gingival tissues, face and smile. The paradigms that emerged and evolved from these efforts were intended to make the science and clinical practice in dental esthetics more quantifiable and predictable. Often times, however, a patient's desires and needs require us to compromise and deviate from what would otherwise be considered an ideal treatment plan. In these situations one must be able to predict the outcome of alternative treatment options that may be less than ideal, and for this reason it is important to understand their limitations.

In the restoration or replacement of maxillary incisors, the clinician must first determine what is required to achieve a successful treatment outcome. Currently, the gold standard for this has been the diagnostic wax-up. A diagnostic wax-up is defined by the glossary of prosthodontic terms as a dental diagnostic procedure in which planned restorations are developed in wax on a diagnostic cast to determine optimal clinical and laboratory procedures necessary to achieve the desired esthetics and function.[70] Whether digital or analogue, diagnostic wax-ups are used to identify the size, shape, morphology, orientation, and location of the tooth being restored. It provides a road map for treatment planning as well as an esthetic prognosis for clinical success. However, despite the utility of diagnostic wax-ups, almost nothing has been reported in the dental literature regarding their limitations.

Currently, the only way to predict esthetic success for restoring or replacing a single maxillary incisor in compromised spacing situations is to complete a diagnostic wax-up. There are variety of adjustments and manipulations to the form of a tooth that can compensate for different spacial discrepancies in the esthetic zone. The transitional line angles, embrasures, proximal contacts, width/length proportions, incisal edge morphology, all directly influence the esthetic perception of the clinical crowns and can be used to improve the esthetic restoration of a less than ideal spacing situation. The extent to which these adjustments can compensate for a spacial deficiency has never been reported in the dental literature.

With digital workflow and CAD/CAM production of dental crowns becoming more widely used than ever before, studies that incorporate these technologies into their design would provide a direct link between research and the clinical application of digital technologies in dentistry. Furthermore, it would provide valuable feedback to engineers and developers of CAD/CAM technologies on how to streamline and improve digital dental technologies as well as their application. For example, the virtual design tools and tooth mould libraries available in digital design software enable the user to produce excellent restorations with a very high level of accuracy, there is a significant learning curve for new users and sometimes even doing something as simple as manipulating the digital model to see it from multiple perspectives can take time to master. Furthermore, an entirely digital workflow can sometimes make it difficult to make dimensional measurements or diagnostic markings such as midline, occlusal plane or desired gingival contours. In other words, transitioning from analogue to digital takes time and improving the intuitiveness of the digital workflow could help improve treatment outcomes for new users.

There is a problem in the way we have studied dental esthetics in the past and that problem lies in the inherent difference between how a study participant views a series of images of altered smiles and how discerning they would be if they were in our dental chair receiving treatment that altered their own dental esthetics. For this reason, there needs to be research conducted on what the human eye is capable of perceiving when looking at known isolated alterations in dental esthetics; and furthermore, whenever possible, the study design should incorporate direct links with the actual clinical and technical fabrication processes currently being used to treat patients today. The purpose of this research study is to determine the range (in millimeters) of spacial discrepancies for a single missing maxillary incisor, in which digital restoration of the missing tooth produces: (1) no perceivable discrepancy, or (2) a result that would be considered unacceptable by patients and dental professionals respectively.

MATERIALS AND METHODS

An anonymous electronic survey was created and administered in which participants were asked to look at a series of carefully modified digital models of a maxillary arch, and then assess differences in width of two teeth, labelled "A" and "B" on each model and rate the overall appearance of the teeth. The digital models were fabricated from a diagnostic cast of an individual meeting the following criteria: good oral health, natural dentition, no visible restorations, relatively good dental esthetics, and no history of orthodontic treatment. Figure 1 provides an illustration of the sequence of computer aided design used in generating the digital control model. One of the "virtual" maxillary incisors from the control model was then removed and the mesiodistal width of the "edentulous" site was altered to create 16 different experimental models with restorative space discrepancies ranging from -2.0 mm, -1.5mm, -1.0mm, -0.5mm, +0.5mm, +1.0mm, +1.5mm, and +2.0mm, compared to the control. A digital wax up was then fabricated with the intention of compensating for the width discrepancy by altering line angles, contours, and wrapping interproximal contacts with the adjacent teeth. All changes in total mesiodistal width of the anterior segment were compensated for by altering the width of the premolars. Images of the control and 16 experimental digital models appear in Figures 2-18. Survey participants only viewed the digital models from the frontal and lateral perspectives; they never saw the occlusal view for any of the digital models.

Electronic Survey

The electronic survey used in this study was administered through Qualtrics (Qualtrics LLC, Provo, UT). Participants provided their approximate age range, whether or not they considered themselves a dental professional, and if so they were asked to identify themselves as one of the following: General Dentist, Endodontist, Oral and Maxillofacial Pathologist, Oral and Maxillofacial Radiologist, Oral and Maxillofacial Surgeon, Orthodontist, Pediatric Dentist, Periodontist, Prosthodontist, Dental Public Health Professional, Dental Hygienist, Dental Lab Technician, Dental Assistant, Dental Office Administrative Personnel, Dental Student (1st year), Dental Student (2nd year), Dental Student (3rd year), Dental Student (4th year), or Other. The survey provided written instructions and participants confirmed that they understood the instructions before beginning the survey. Participants then viewed three images (frontal, left lateral, and right lateral views) for each of the17 digital models included in the survey and were asked the same two questions:

Question 1: Looking at the pictures above, how would you compare the width of crown A to the width of crown B?

- ❍ A is much smaller than B
- ❍ A is slightly smaller than B
- ❍ A and B are the same width
- ❍ A is slightly wider than B
- ❍ A is much wider than B

Question 2: How would you describe the esthetics of crowns A and B?

- ❍ Unacceptable
- ❍ Poor
- ❍ Fair
- ❍ Good
- ❍ Excellent

Digital Model Fabrication

An irreversible hyrdocolloid (Jeltrate® Plus Dustless, Dentsply, Milford, DE) impression was made from an individual meeting the following criteria: good oral health, natural dentition, no visible restorations, relatively good dental esthetics, and no history of orthodontic treatment.

The diagnostic cast was poured in Type IV dental stone (Silky Rock, Whip Mix, Louisville, KY), and measurements of the width of the anterior teeth were recorded using a Boley gauge (Miltex 68-694 Stainless, Germany). The mesiodistal widths recorded were: centrals = 8.2mm, laterals = 6.5mm, and canines = 7.5mm. Measurements were repeated three times by the primary investigator on three separate occasions, and the results verified that the diagnostic cast had absolutely no mesiodistal width discrepancies. The diagnostic cast was then duplicated using an addition-vulcanizing duplication silicone (Z-Dupe, Henry Schein®, Germany) and a duplicate cast poured in the same Type IV dental stone (Silky Rock, Whip Mix, Louisville, KY). The duplicated cast was then modified by removing teeth #6-11, smoothing the gingival tissues and proximal papilla, and preparing the premolars for a #5-12 FDP restoration. A scan of the modified duplicate cast can be seen in Figure 1B.

An extraoral scanner with active triangulation (D810, 3Shape®, Copenhagen, Denmark; EAT) was used to scan the diagnostic cast as the pre-preparation scan (Figure 1A), and the modified duplicate cast was scanned as the preparation scan (Figure 1B). The digital restorations #5-12 were designed using 3Shape® Dental System 2016, and selected steps from this process are illustrated in Figures 1A-E. A standardized tooth mould was selected from the 3Shape® "smile library" (VITA T3M RealView). The "virtual restorations" were designed by superimposing the scans of the two casts and carefully changing the position, orientation and dimensions of the virtual teeth to match the natural teeth. No modifications affecting individual tooth morphology were made in order to ensure that the "virtual restorations" displayed excellent symmetry across the anterior teeth, while maintaining the same mesiodistal widths and similar relative proportions as the natural teeth from the diagnostic cast. This "virtually" restored model became the digital control model. This control model was then altered to create 16 experimental models in which a mesiodistal width discrepancy of one maxillary incisor (central or lateral) was altered.

The 16 digital experimental models generated for the survey were made by duplicating the control file and removing a single maxillary central or lateral incisor. The mesiodistal width of the edentulous space was then altered by moving the position and orientation of the adjacent teeth. Changes in the maxillary premolars were made to compensate for the corresponding changes in inter-arch width. The mesiodistal width of the single missing maxillary central or lateral incisor was then altered by 0.5mm increments to create single tooth mesiodistal width discrepancies of -2.0 mm, -1.5mm, -1.0mm, -0.5mm, +0.5mm, +1.0mm, +1.5mm, and +2.0mm. Finally, a digital wax up was then fabricated with the intention of compensating for the mesiodistal width discrepancy by altering line angles, contours, and wrapping interproximal contacts with the adjacent teeth. Images of the control and 16 experimental digital models appear in Figures 2-18. Occlusal views demonstrate the waxing techniques used to compensate for the actual mesiodistal width discrepancy, however survey participants only viewed the digital models from the frontal and lateral perspectives. They never saw the occlusal view for any of the digital models.

Recruitment

Participants were recruited by the principle investigator through the University of North Carolina at Chapel Hill School of Dentistry. The only exclusion criteria was the participant's willingness and ability to complete the electronic survey. Participants were asked if they would complete a 10 minute survey in which they would look at images of digital models of teeth, compare the width of two teeth labelled “A” and “B” and then rate the overall appearance of the teeth. After providing verbal consent, the survey was administered on a laptop computer via an anonymous Qualtrics survey portal link. All participants had direct contact with the primary investigator to ensure that instructions for the survey were clear. Once participants affirmed that they understood the instructions and started the survey, no further assistance or instruction was provided. No influence or consultation was provided at anytime during the survey so that the participants used their own criteria to judge width discrepancies and esthetics.

DATA ANALYSIS:

Statistical analysis of the data was performed using PROC FREQ (SAS v. 9.4). Fisher’s exact test was used to determine if there was a statistically significant difference between groups (layperson vs dental) in the proportionality of responses to judgement of width discrepancy and esthetic perception. Statistical significance was set at a P value < or = 0.05. Descriptive statistics were then used to report the responses from participants on their judgement of actual width discrepancy as well as perceived esthetics for the crowns for each of the digital models.

RESULTS:

A total of 108 participants, consisting of 40 laypersons and 68 dental professionals were recruited directly by the principle investigator through the UNC Chapel Hill School of Dentistry. Demographic data are included in Table 1. Participants were recruited at random and the only exclusion criteria for recruitment was based on each participant’s willingness and ability to complete the electronic survey. The purpose of the primary investigator having direct interaction with the participants was to ensure that participants understood the written instructions provided at the beginning of the survey. Once participants affirmed that they understood the instructions no further assistance, instruction or influence was provided. The survey completion rate was 94.4%, with102 out of the108 participants who started the survey completing all of the questions. The completed responses from the participants who did not complete the entire survey were still included in the data analysis.

The "actual" width discrepancies reported below refer to the difference, in millimeters, between the mesiodistal restorative space available for the digital wax-up and the width of the contralateral tooth. Fisher's exact test was used to determine if there was a statistically significant difference between groups (layperson vs dental) in the proportionality of responses to judgement of width discrepancy and esthetic perception. Statistical significance was set at a P value < or = 0.05.

The results from the electronic survey indicate a range of actual mesiodistal width discrepancy for a central incisor (-1.5mm to +1.0mm) and lateral incisor (-1.0mm to +0.5mm) for which a digital wax-up was considered esthetically acceptable by at least 95% of laypersons. Digital wax-ups restoring asymmetric width discrepancies of +2.0mm were recognized by nearly all participants and esthetically considered poor and unacceptable by 74.6-77.3% of dental professionals and 33-48% of laypersons.

From the results of Fishers exact test, there were statistically significant differences between laypersons and dental professionals in their proportional responses regarding perception of width discrepancy for digital wax-ups replacing single missing central incisors having actual mesiodistal width discrepancies of +1.0mm (p = 0.0177), +1.5mm (p = 0.0326), and +2.0mm (p = 0.0002) (Table 2A). There were also statistically significant differences between laypersons and dental professionals regarding their perception of width discrepancy for digital wax-ups replacing single missing lateral incisors having actual mesiodistal width discrepancies of +1.0mm (p = 0.0005), +1.5mm (lateral incisor p = 0.0025), and +2.0mm (p = 0.0337) (Table 2B).

Further significant differences were noted between laypersons and dental professionals regarding their perception of poor and unacceptable esthetics for digital wax-ups replacing single missing central incisors with actual mesiodistal width discrepancies of +2.0mm (p = 0.0009) and -2.0mm (p = 0.0208) (Table 3A). There were also statistically significant differences between laypersons and dental professionals in their their perception of poor and unacceptable esthetics for digital wax-ups replacing single missing lateral incisors with actual mesiodistal width discrepancies of +1.0mm (p = 0.0408), +1.5mm (p = 0.0141), and +2.0mm (p = 0.0337) (Table 3B).

Statistical analysis (Fisher’s exact test) showed no statistically significant differences between laypersons and dental professionals in their proportional responses regarding perception of width discrepancy for digital wax-ups replacing single missing maxillary central incisors when the edentulous site being restored had actual mesiodistal width discrepancies of -2.0mm (p = 0.0644), -1.5mm (p = 0.1760), -1.0mm (p = 0.3154), -0.5mm (p = 0.7245), +0.5mm (p = 0.7033), as well as for the Control with 0mm discrepancy (p = 0.7133) (Table 2A).

Statistical analysis (Fisher’s exact test) showed no statistically significant differences between laypersons and dental professionals in their proportional responses regarding perception of width discrepancy for digital wax-ups replacing single missing maxillary lateral incisors when the edentulous site being restored had actual mesiodistal width discrepancies of -2.0mm ($p = 0.5780$), -1.5mm ($p = 0.1334$), -1.0mm ($p = 0.4346$), -0.5mm ($p = 0.9636$), +0.5mm ($p = 0.7815$), as well as for the Control with 0mm discrepancy ($p = 0.7829$) (Table 2B).

Statistical analysis (Fisher's exact test) showed no statistically significant differences between laypersons and dental professionals in their proportional responses regarding perception of poor and unacceptable esthetics for digital wax-ups replacing single missing maxillary central incisors when the edentulous site being restored had actual mesiodistal width discrepancies of -1.5mm ($p = 0.1573$), -1.0mm ($p = 0.0895$), -0.5mm ($p = 0.7136$), and +1.0mm ($p = 0.3440$), +1.5mm ($p = 0.0938$), as well as for the Control with 0mm discrepancy ($p = 0.9782$) (Table 3A).

Statistical analysis (Fisher's exact test) showed no statistically significant differences between laypersons and dental professionals in their proportional responses regarding perception of poor and unacceptable esthetics for digital wax-ups replacing single missing maxillary lateral incisors when the edentulous site being restored had actual mesiodistal width discrepancies of -2.0mm ($p = 0.2833$), -1.5mm ($p = 0.3858$), -1.0mm ($p = 0.5936$), -0.5mm ($p = 0.4125$), +0.5mm ($p = 0.9351$), as well as for the Control with 0mm discrepancy ($p = 0.7840$) (Table 3B).

For the control model with no mesiodistal width discrepancies 71.8% of laypersons and 61.8% of dental professionals accurately reported no apparent width discrepancy for the central incisors, and 75.0% of laypersons and 69.8% of dental professionals accurately reported no apparent width discrepancy for the central incisors. There was no statistical significance between groups for any of the control variables. Regarding the perceived esthetics of the control model 0% of laypersons and 1.5-1.6% of dental professionals rated the esthetics of the control model as being poor and unacceptable.

DISCUSSION

There is a confounding quandary in the way researchers have studied dental esthetics in the past and that problem lies in the inherent difference between how a study participant views a series of images of altered smiles and how discerning they would otherwise be if they were in the dental chair receiving treatment that altered their own dental esthetics. For this reason, there needs to be research conducted on what the human eye is capable of perceiving when looking at known and isolated alterations in dental esthetics; and furthermore, whenever possible, the study design should incorporate direct links with the actual clinical and technical fabrication processes currently being used to treat patients today.

The anonymous electronic survey was successful in demonstrating statistically significant differences between laypersons and dental professionals in their perceptibility and esthetic assessment of dental discrepancies, especially with increasing amounts of dental discrepancy. For both maxillary central and lateral incisors, positive asymmetric width discrepancies of +1.0mm, +1.5mm and +2.0mm were more noticeable to dental professionals compared to laypersons. For maxillary lateral incisors, positive asymmetric width discrepancies of +1.0mm, +1.5mm and +2.0mm were also rated less esthetic by dental professionals compared to laypersons. For maxillary centrals, width discrepancies of +2.0mm and -2.0mm were rated less esthetic by dental professionals compared to laypersons. These results confirm findings from previous studies that dental professionals are more perceptive than laypersons at perceiving dental discrepancies especially with increasing degrees of asymmetry or discrepancy.

Descriptive statistics revealed several observations that provide strong evidence to support a method for predicting the likelihood that a diagnostic wax-up for a single maxillary incisor with compromised asymmetrical mesiodistal spacing will be esthetically successful. By simply measuring the mesiodistal space of the site to be restored and comparing it to the contralateral tooth, one can quickly determine whether or not a diagnostic wax-up has a chance of being considered esthetic by the patient.

The data suggests that for a properly contoured diagnostic wax-up of a maxillary incisor with a mesiodistal width discrepancy measuring -0.5mm to +0.5mm, 0-1% of patients will perceive the esthetics as being poor or unacceptable. For a properly contoured diagnostic wax-up of a maxillary central incisor with a mesiodistal width discrepancy measuring -1.5mm to +1.0mm, approximately 2.5% to 5% of patients will perceive the esthetics as being poor or unacceptable. For a properly contoured diagnostic wax-up of a maxillary lateral incisor with a mesiodistal width discrepancy measuring -1.0mm to +0.5mm, approximately 0 to 2.5% of patients will perceive the esthetics as being poor or unacceptable. Thus it can be stated that for asymmetric mesiodistal width discrepancies of the maxillary incisors, the range of feasibility, in which a diagnostic wax-up will have a 95% chance of being successful for central incisors is -1.5mm to +1.0mm, while for lateral incisors is -1.0mm to +0.5mm. Outside the limits of these mesiodistal width discrepancies for maxillary incisors, the percent of patients that will perceive the resulting restorations as poor and unacceptable will jump to >10%. It is then at the discretion of the restorative dentist and their patient whether or not to pursue alternative treatment options such as orthodontics or including more teeth in the treatment plan to achieve better spacial relationships.

CONCLUSIONS:

Although dimensional and esthetic perceptions of individual patients vary, the results from this study indicate a range of actual mesiodistal width discrepancy for central incisors (-1.5mm to +1.0mm) and lateral incisors (-1.0mm to +0.5mm) for which a digital wax-up will be considered esthetically acceptable by 95% of patients. These ranges can be used as a quick method for assessing whether to attempt a diagnostic wax-up for a single maxillary incisor with compromised mesiodistal restorative space, or to consider other treatment options that will provide a better esthetic outcome.

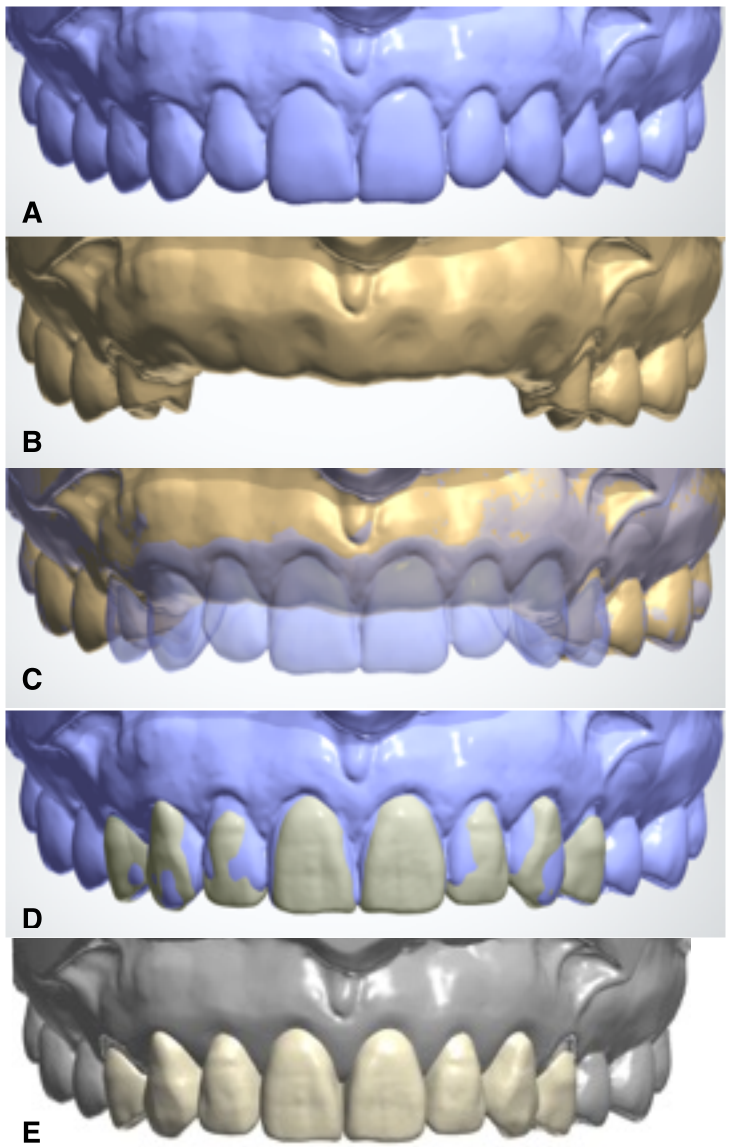

FIGURE 1 - (A) Scanned diagnostic cast, (mesiodistal width of centrals = 8.2mm, laterals = 6.5mm, and canines = 7.5mm), **(B)** Modified diagnostic cast with prepared teeth #5 and #12, **(C)** diagnostic cast superimposed over modified cast, **(D)** Digital restorations for control model superimposed over diagnostic cast, **(E)** Control model.

Figure 2A Images used in survey of the digital control model with no mesiodistal width discrepancies.

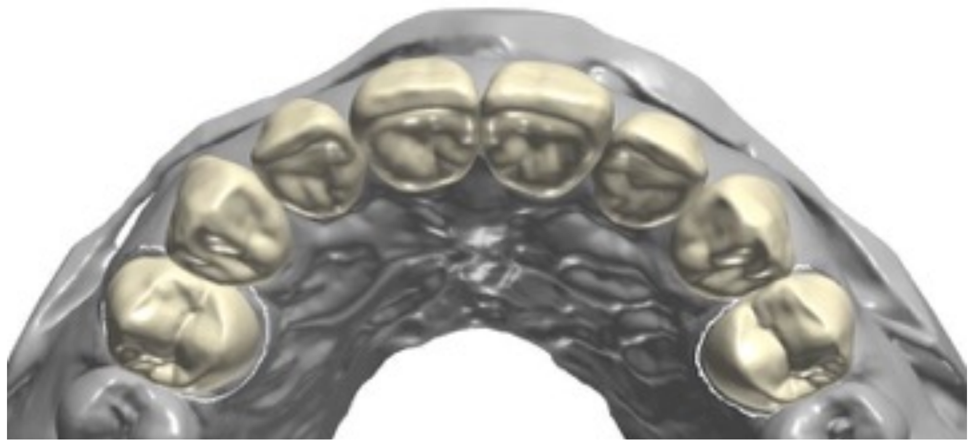

Figure 2B Occlusal view of the digital control model with no mesiodistal width discrepancies. Participants did not see occlusal views of any of the digital models.

Figure 3A Images seen and assessed by participants in survey of digital model where the mesiodistal restorative space of site #8 was reduced -2.0mm and #8 restored by digital wax-up.

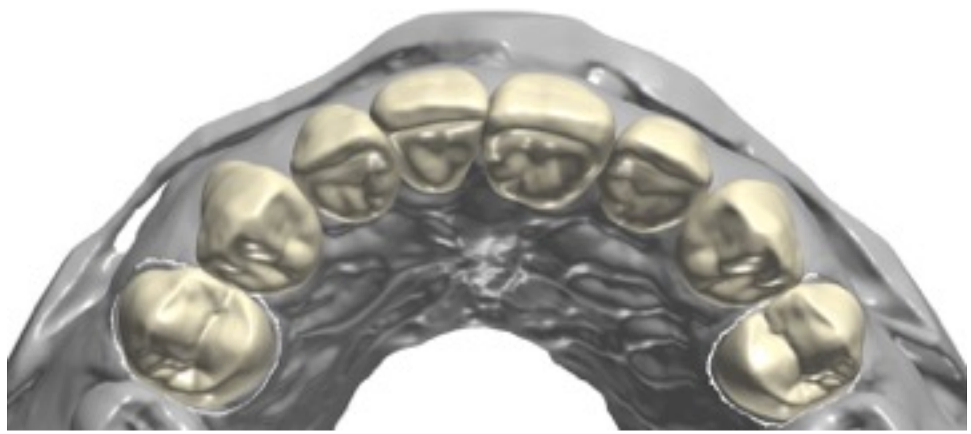

Figure 3B Occlusal view of digital model where the mesiodistal restorative space of site #8 was reduced -2.0mm and #8 restored by digital wax-up. This image was not in the survey.and was not seen by participants.

Figure 4A Images seen and assessed by participants in survey of digital model where the mesiodistal restorative space of site #10 was reduced -2.0mm and #10 restored by digital wax-up.

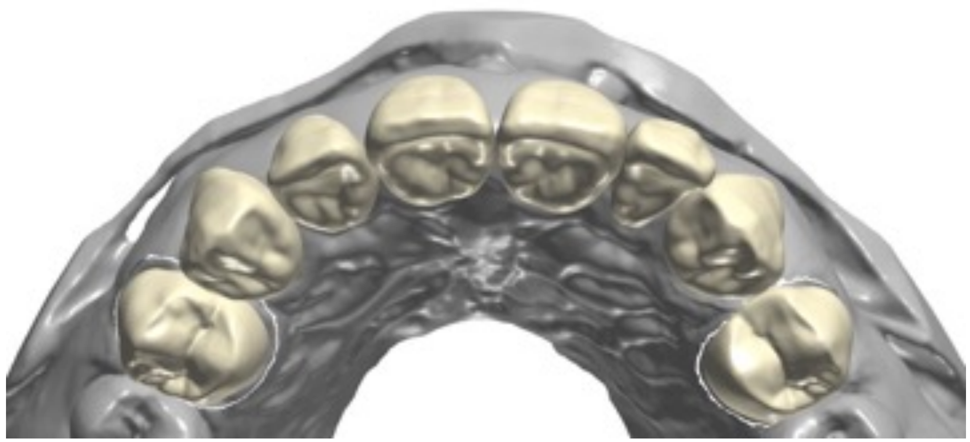

Figure 4B Occlusal view of digital model where the mesiodistal restorative space of site #10 was reduced -2.0mm and #10 restored by digital wax-up. This image was not in the survey.and was not seen by participants.

Figure 5A Images seen and assessed by participants in survey of digital model where the mesiodistal restorative space of site #9 was reduced -1.5mm and #9 restored by digital wax-up.

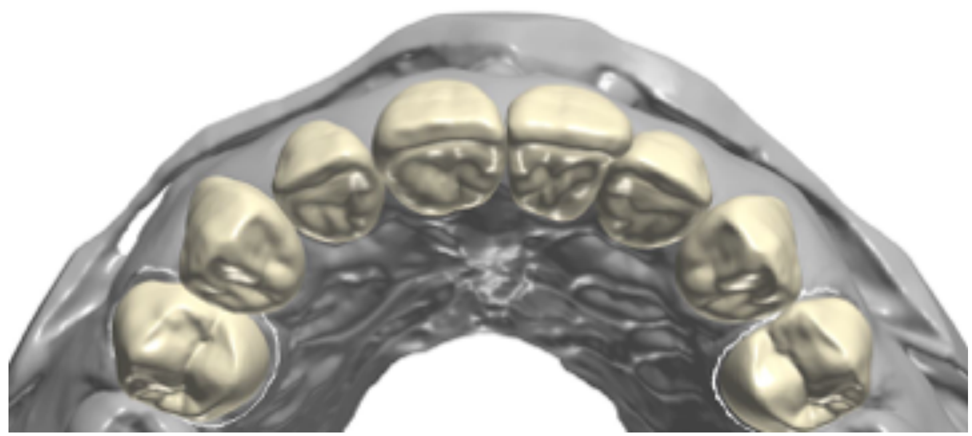

Figure 5B Occlusal view of digital model where the mesiodistal restorative space of site #9 was reduced -1.5mm and #9 restored by digital wax-up. This image was not in the survey.and was not seen by participants.

Figure 6A Images seen and assessed by participants in survey of digital model where the mesiodistal restorative space of site #7 was reduced -1.5mm and #7 restored by digital wax-up.

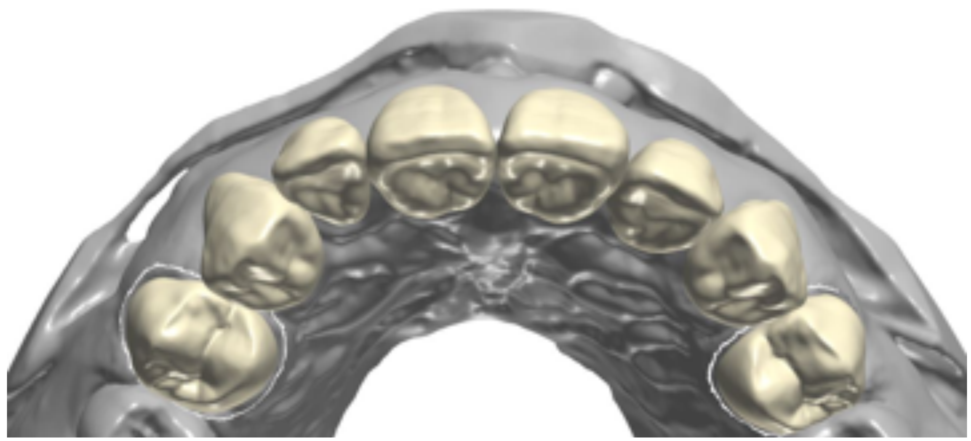

Figure 6B Occlusal view of digital model where the mesiodistal restorative space of site #7 was reduced -1.5mm and #7 restored by digital wax-up. This image was not in the survey.and was not seen by participants.

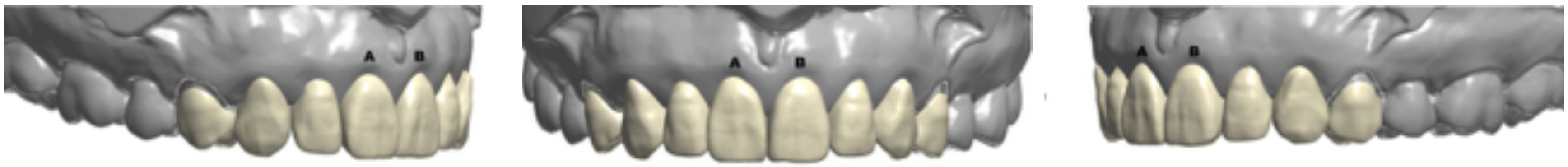

Figure 7A Images seen and assessed by participants in survey of digital model where the mesiodistal restorative space of site #8 was reduced -1.0mm and #8 restored by digital wax-up.

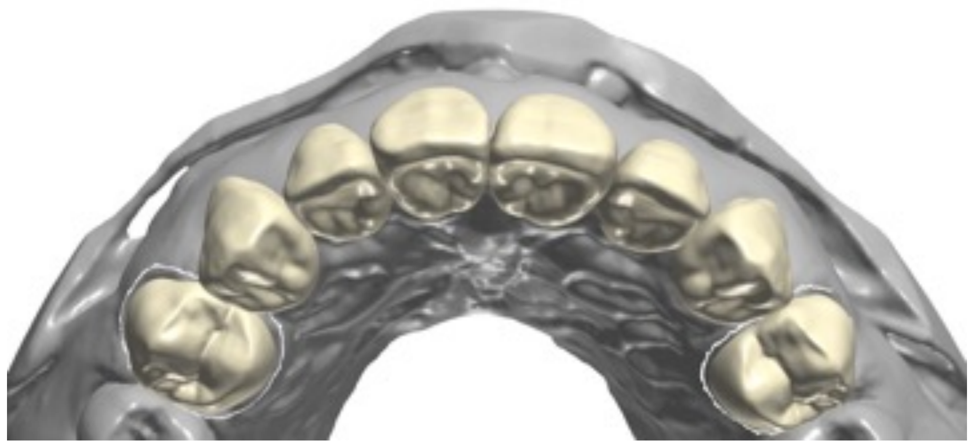

Figure 7B Occlusal view of digital model where the mesiodistal restorative space of site #8 was reduced -1.0mm and #8 restored by digital wax-up. This image was not in the survey.and was not seen by participants.

Figure 8A Images seen and assessed by participants in survey of digital model where the mesiodistal restorative space of site #10 was reduced -1.0mm and #10 restored by digital wax-up.

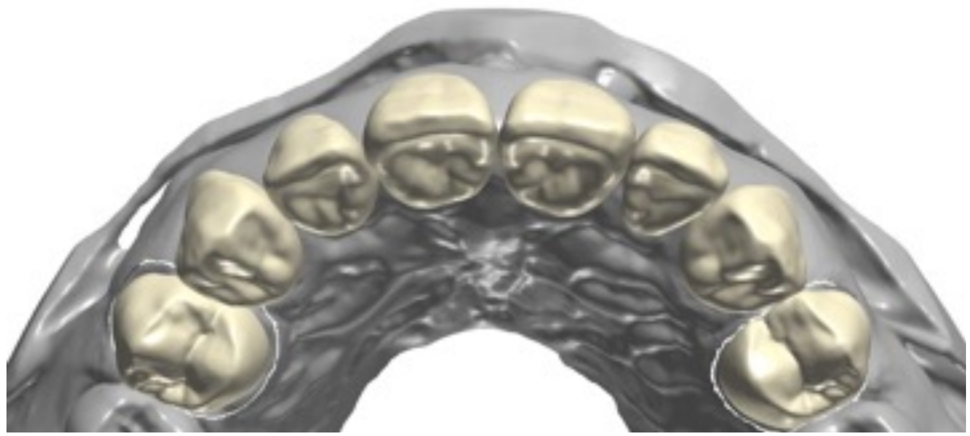

Figure 8B Occlusal view of digital model where the mesiodistal restorative space of site #10 was reduced -1.0mm and #10 restored by digital wax-up. This image was not in the survey.and was not seen by participants.

Figure 9A Images seen and assessed by participants in survey of digital model where the mesiodistal restorative space of site #9 was reduced -0.5mm and #9 restored by digital wax-up.

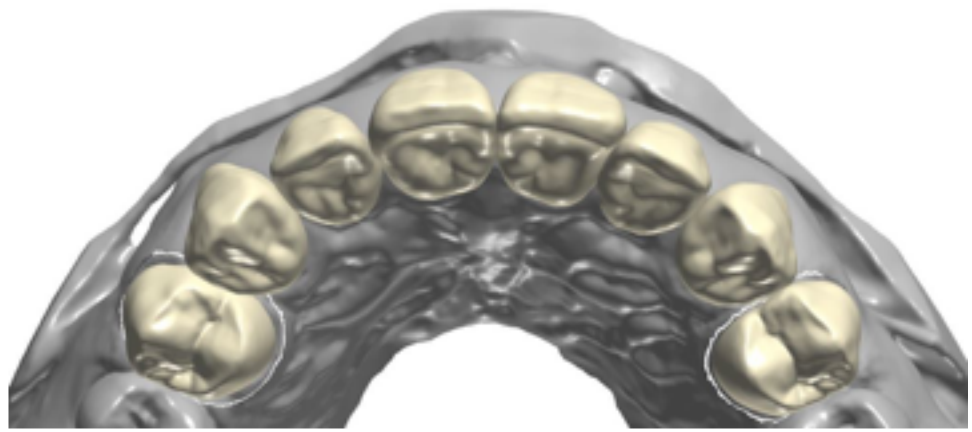

Figure 9B Occlusal view of digital model where the mesiodistal restorative space of site #9 was reduced —0.5mm and #9 restored by digital wax-up. This image was not in the survey.and was not seen by participants.

Figure 10A Images seen and assessed by participants in survey of digital model where the mesiodistal restorative space of site #7 was reduced -0.5mm and #7 restored by digital wax-up.

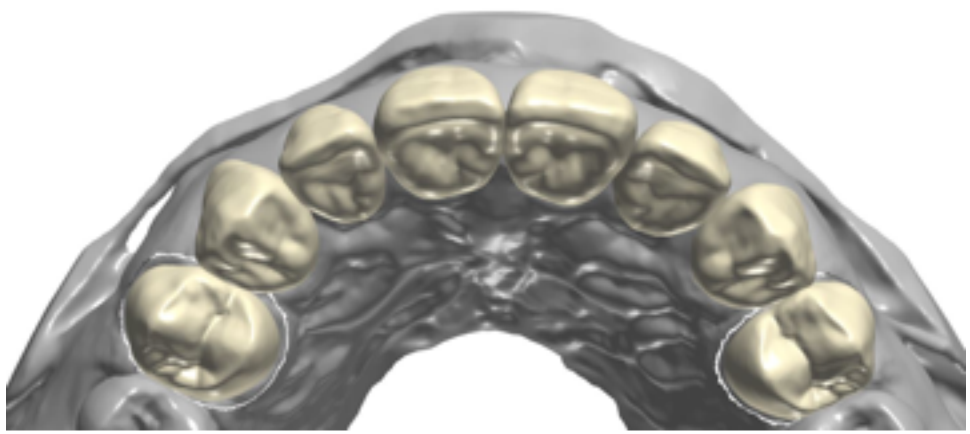

Figure 10B Occlusal view of digital model where the mesiodistal restorative space of site #7 was reduced -0.5mm and #7 restored by digital wax-up. This image was not in the survey.and was not seen by participants.

Figure 11A Images seen and assessed by participants in survey of digital model where the mesiodistal restorative space of site #8 was increased +0.5mm and #8 restored by digital wax-up.

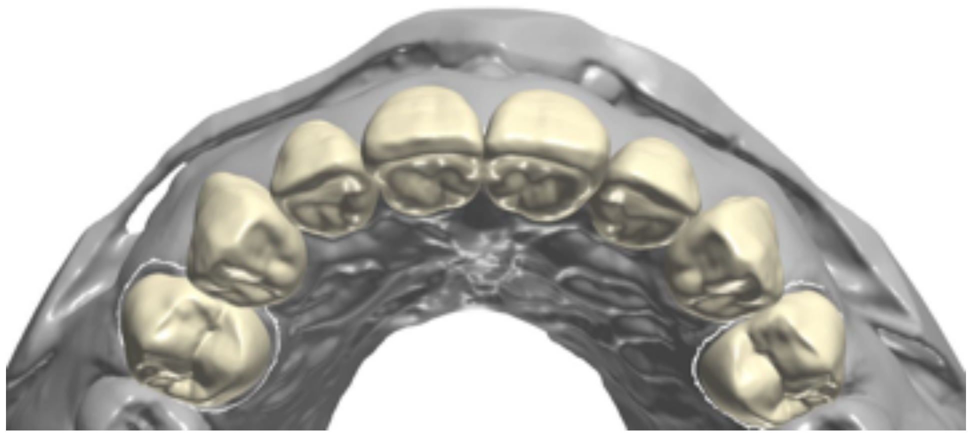

Figure 11B Occlusal view of digital model where the mesiodistal restorative space of site #8 was increased +0.5mm and #8 restored by digital wax-up. This image was not in the survey.and was not seen by participants.

Figure 12A Images seen and assessed by participants in survey of digital model where the mesiodistal restorative space of site #10 was increased +0.5mm and #10 restored by digital wax-up.

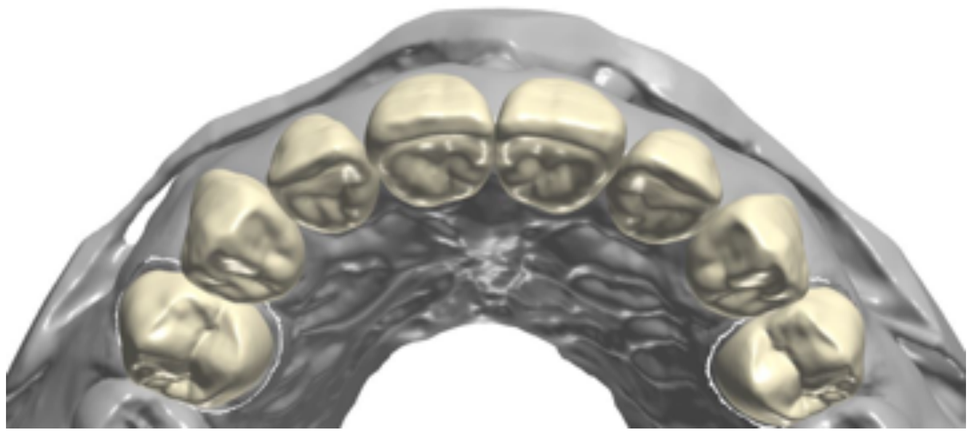

Figure 12B Occlusal view of digital model where the mesiodistal restorative space of site #10 was increased +0.5mm and #10 restored by digital wax-up. This image was not in the survey.and was not seen by participants.

Figure 13A Images seen and assessed by participants in survey of digital model where the mesiodistal restorative space of site #9 was increased +1.0mm and #9 restored by digital wax-up.

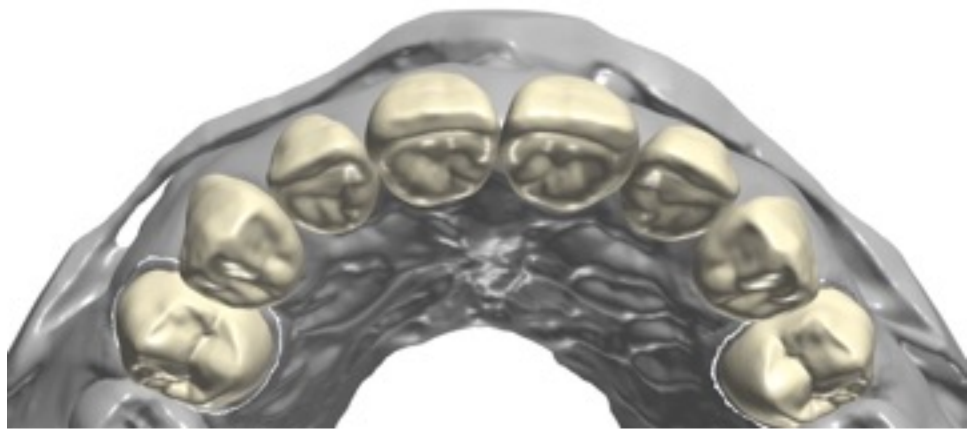

Figure 13B Occlusal view of digital model where the mesiodistal restorative space of site #9 was increased +1.0mm and #9 restored by digital wax-up. This image was not in the survey.and was not seen by participants.

Figure 14A Images seen and assessed by participants in survey of digital model where the mesiodistal restorative space of site #7 was increase +1.0mm and #7 restored by digital wax-up.

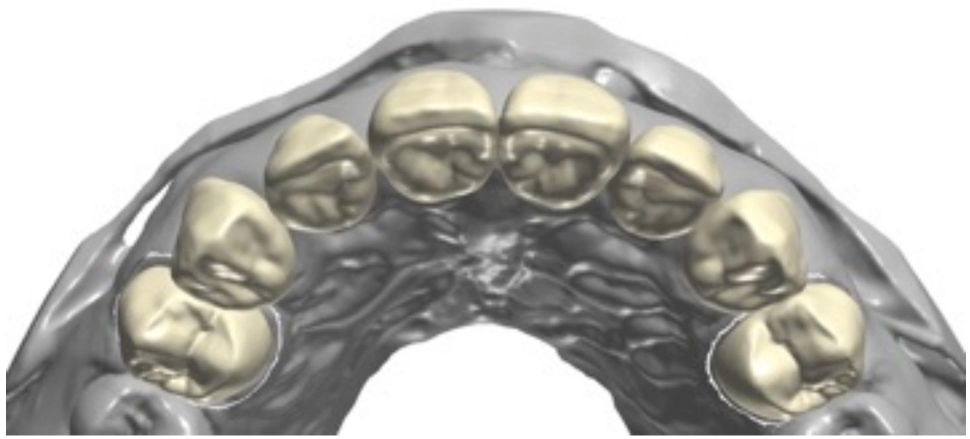

Figure 14B Occlusal view of digital model where the mesiodistal restorative space of site #7 was increased +1.0mm and #7 restored by digital wax-up. This image was not in the survey.and was not seen by participants.

Figure 15A Images seen and assessed by participants in survey of digital model where the mesiodistal restorative space of site #8 was increased +1.5mm and #8 restored by digital wax-up.

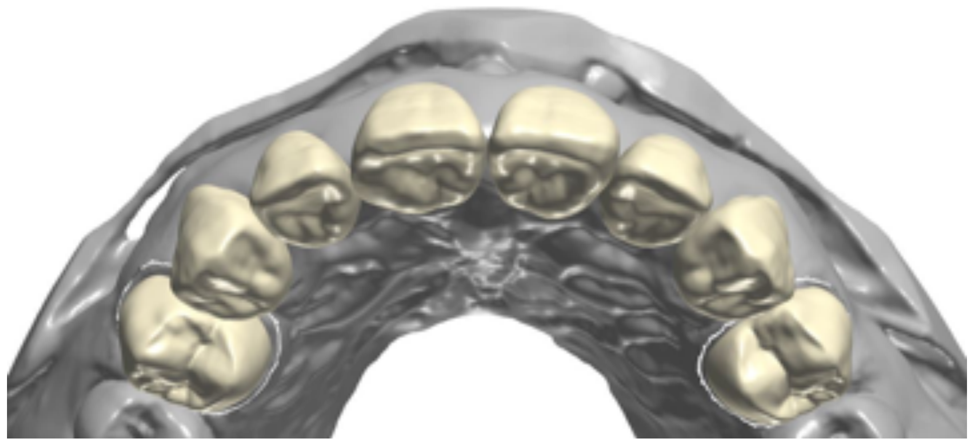

Figure 15B Occlusal view of digital model where the mesiodistal restorative space of site #8 was increased +1.5mm and #8 restored by digital wax-up. This image was not in the survey.and was not seen by participants.

Figure 16A Images seen and assessed by participants in survey of digital model where the mesiodistal restorative space of site #10 was increased +1.5mm and #10 restored by digital wax-up.

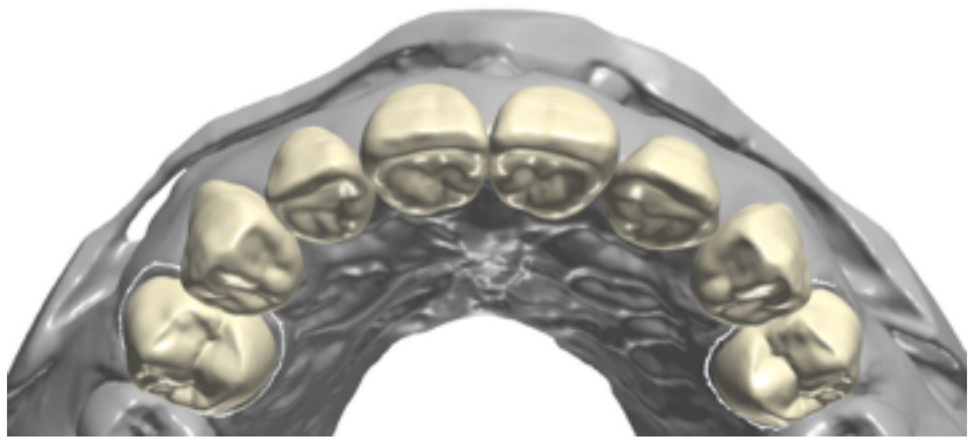

Figure 16B Occlusal view of digital model where the mesiodistal restorative space of site #10 was increased +1.5mm and #10 restored by digital wax-up. This image was not in the survey.and was not seen by participants.

Figure 17A Images seen and assessed by participants in survey of digital model where the mesiodistal restorative space of site #9 was increased +2.0mm and #9 restored by digital wax-up.

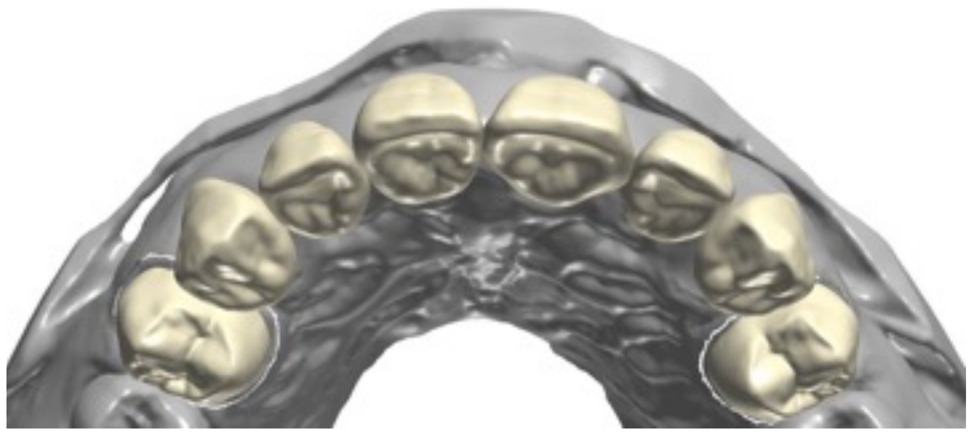

Figure 17B Occlusal view of digital model where the mesiodistal restorative space of site #9 was increased +2.0mm and #9 restored by digital wax-up. This image was not in the survey.and was not seen by participants.

Figure 18A Images seen and assessed by participants in survey of digital model where the mesiodistal restorative space of site #7 was increase +2.0mm and #7 restored by digital wax-up.

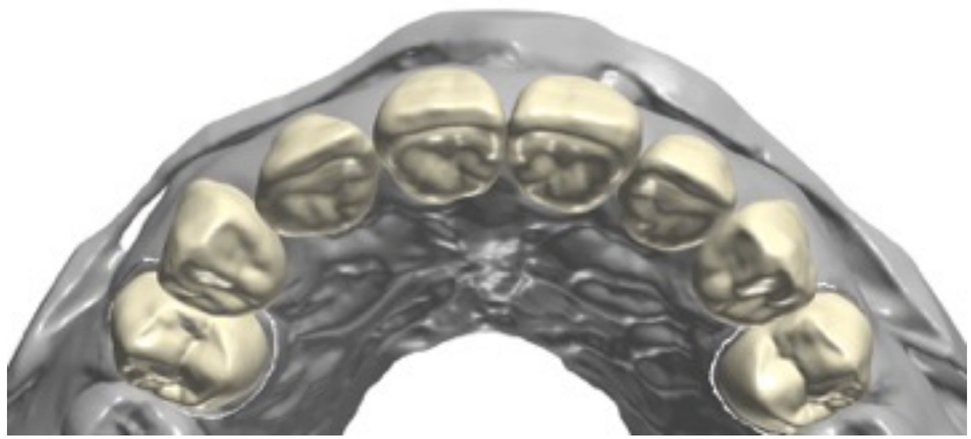

Figure 18B Occlusal view of digital model where the mesiodistal restorative space of site #7 was increased +2.0mm and #7 restored by digital wax-up. This image was not in the survey.and was not seen by participants.

Participant Demographics		
	N	Percent
Total Participants	108	100
Participants who completed all survey questions	102	94.44
Age		
<30yrs	28	25.93
30-49yrs	52	48.15
50-69yrs	27	25
>70yrs	1	0.93
Laypersons	40	37.04
Dental Professionals	68	62.96
Dental Assistants	5	7.35
Dental Hygienist	3	4.41
Dental Lab Technician	4	5.88
Dental Student (2nd yr)	2	2.94
Dental Student (3rd yr)	11	16.18
Dental Student (4th yr)	3	4.41
Endodontist	1	1.47
General Dentist	9	13.24
Oral & Maxillofacial Pathologist	1	1.47
Oral & Maxillofacial Radiologist	1	1.47
Orthodontist	2	2.94
Pediatric Dentist	2	2.94
Periodontist	8	11.76
Prosthodontist	16	23.53

Table 1. Demographic information of survey participants.

Participants Indicating No Perceivable Width Discrepancy for Restored Central Incisor									
Actual Width Discrepancy	-2.0mm	-1.5mm	-1.0mm	-0.5mm	Control	+0.5mm	+1.0mm	+1.5mm	+2.0mm
Laypersons (%)	25	20	27.5	55	71.79	62.5	37.5	47.5	0
Dental Professionals (%)	7.58	8.82	16.18	57.35	61.76	63.49	20.9	39.76	1.52
Fisher's Exact Test $p < 0.05$	0.0644	0.1760	0.3154	0.7245	0.7133	0.7033	* 0.0177	* 0.0326	* 0.0002

Participants Indicating No Perceivable Width Discrepancy for Restored Lateral Incisor									
Actual Width Discrepancy	-2.0mm	-1.5mm	-1.0mm	-0.5mm	Control	+0.5mm	+1.0mm	+1.5mm	+2.0mm
Laypersons (%)	12.5	30.77	40	60	75	61.54	25.64	20.51	7.69
Dental Professionals (%)	11.29	14.29	23.81	55.56	69.84	57.14	7.94	9.52	1.59
Fisher's Exact Test $p < 0.05$	0.5780	0.1334	0.4346	0.9636	0.7829	0.7815	* 0.0005	* 0.0025	* 0.0337

Table 2. Percentage of laypersons and dental professionals indicating no perceivable width discrepancy for digitally waxed (A) central incisors and (B) lateral incisors.

*P values <0.05 indicate statistically significant differences between laypersons and dental professionals in their proportional responses regarding perception of width discrepancy

Participants Indicating Poor & Unacceptable Esthetics for Restored Lateral Incisor Width Discrepancy									
Actual Width Discrepancy	-2.0mm	-1.5mm	-1.0mm	-0.5mm	Control	+0.5mm	+1.0mm	+1.5mm	+2.0mm
Laypersons (%)	15	10.26	2.5	0	0	0	15.38	10.26	33.33
Dental Professionals (%)	30.16	23.81	4.76	1.59	1.59	1.61	38.1	33.33	74.6
Fisher's Exact Test $p < 0.05$	0.2833	0.3858	0.5936	0.4125	0.7840	0.9351	* 0.0408	* 0.0141	* 0.0003

Participants Indicating Poor & Unacceptable Esthetics for Restored Central Incisor Width Discrepancy									
Actual Width Discrepancy	-2.0mm	-1.5mm	-1.0mm	-0.5mm	Control	+0.5mm	+1.0mm	+1.5mm	+2.0mm
Laypersons (%)	12.5	2.5	5	1	0	0	5	15.38	47.5
Dental Professionals (%)	28.79	7.35	4.41	0	1.47	0	13.43	25	77.27
Fisher's Exact Test $p < 0.05$	* 0.0208	0.1573	0.0895	0.7136	0.9782	—	0.3440	0.0938	* 0.0009

Table 3. Percentage of laypersons and dental professionals indicating poor and unacceptable esthetics for digitally waxed (A) central incisors and (B) lateral incisors.

*P values <0.05 indicate statistically significant differences between laypersons and dental professionals in their proportional responses regarding perception of poor and unacceptable esthetics.

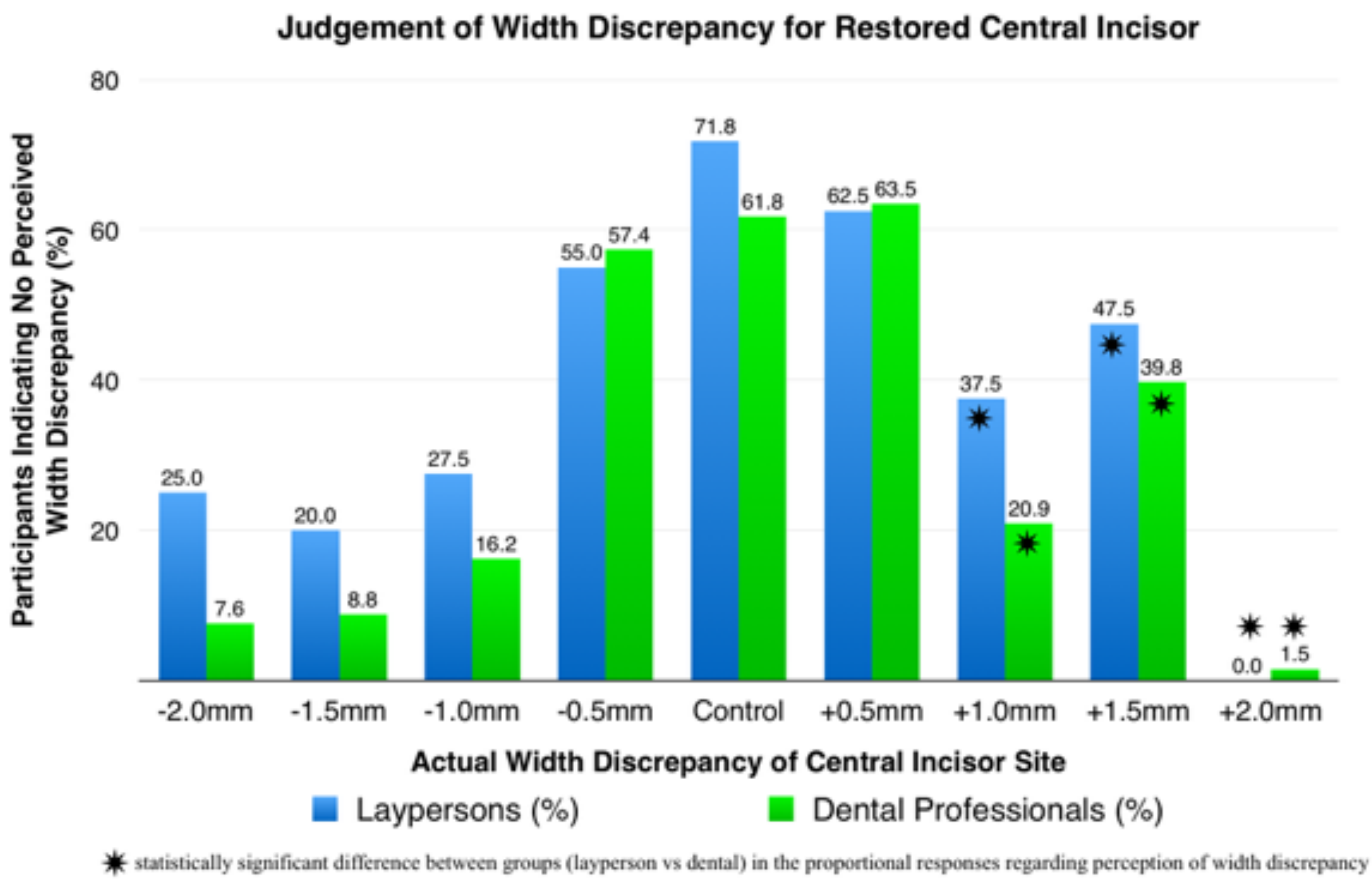

Figure 19 Percentage of laypersons and dental professionals indicating no perceivable width discrepancy for digitally waxed central incisors having an actual width discrepancy of -2.0, -1.5, -1.0, -0.5, 0, +0.5, +1.0, +1.5, and +2.0 millimeters respectively.

*P values <0.05 indicate statistically significant differences between laypersons and dental professionals in their proportional responses regarding perception of width discrepancy.

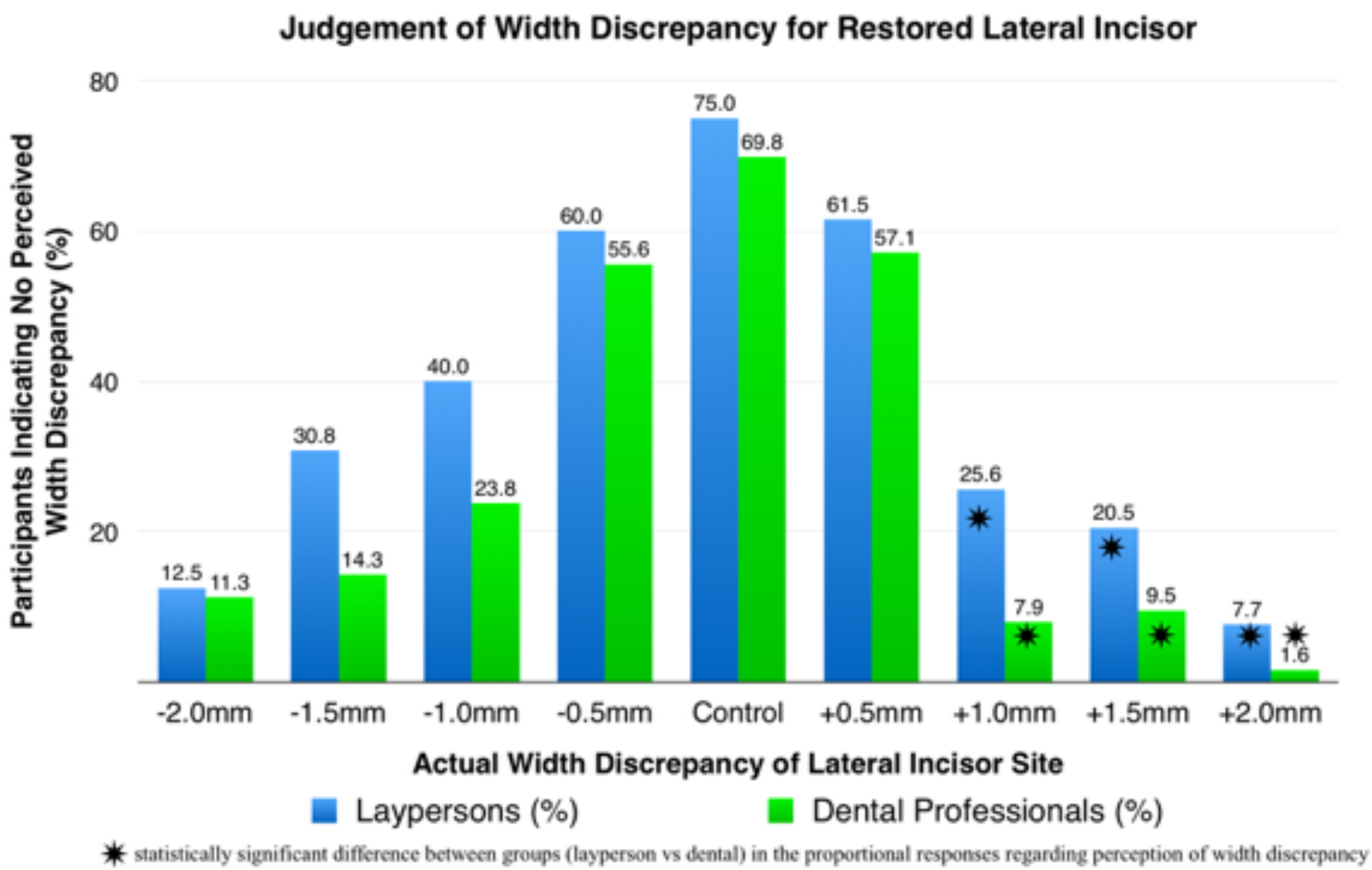

Figure 20 Percentage of laypersons and dental professionals indicating no perceivable width discrepancy for digitally waxed lateral incisors having an actual width discrepancy of -2.0, -1.5, -1.0, -0.5, 0, +0.5, +1.0, +1.5, and +2.0 millimeters respectively.
*P values <0.05 indicate statistically significant differences between laypersons and dental professionals in their proportional responses regarding perception of width discrepancy.

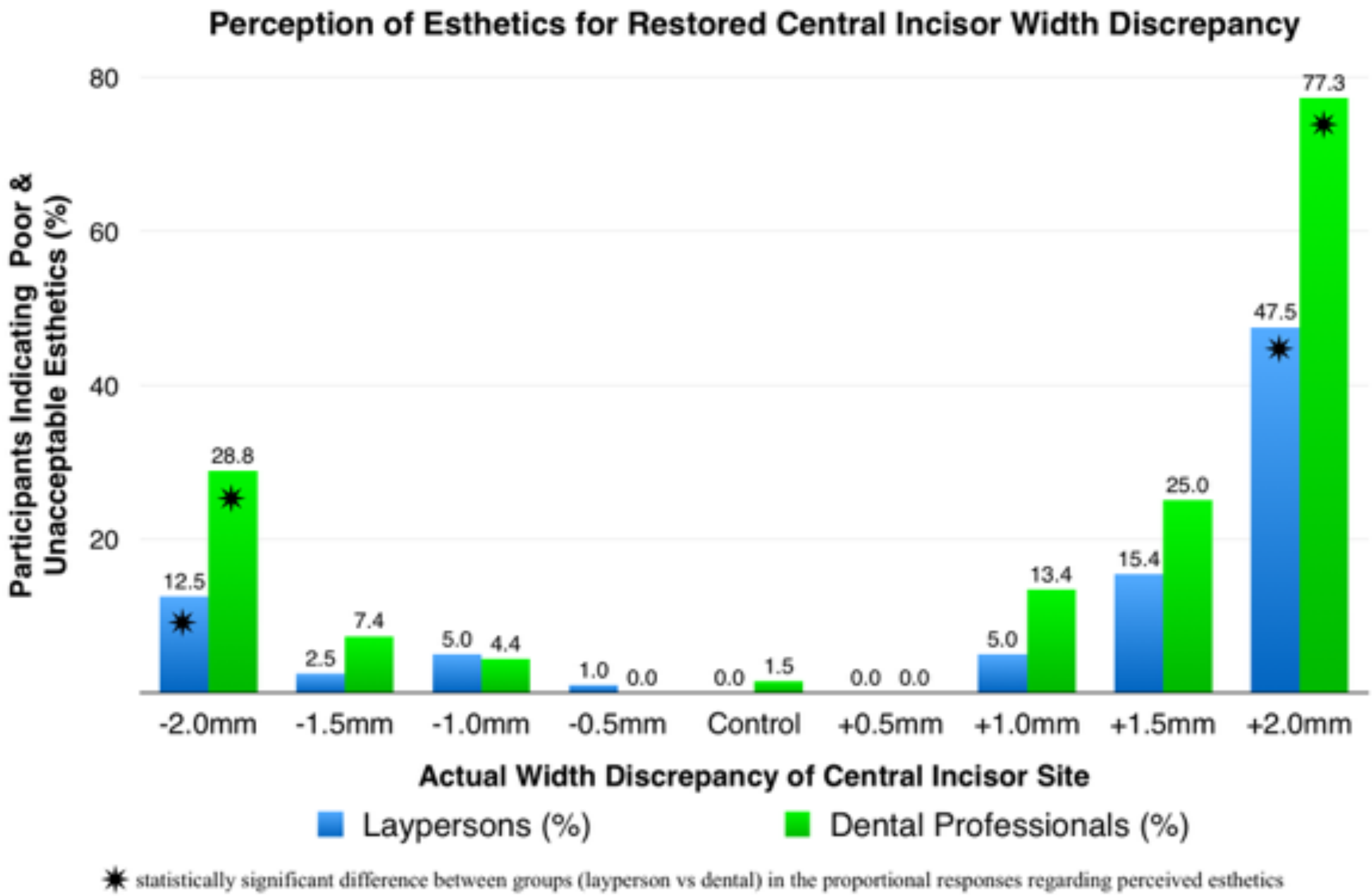

Figure 21 Percentage of laypersons and dental professionals indicating poor and unacceptable esthetics for digitally waxed central incisors having an actual width discrepancy of -2.0, -1.5, -1.0, -0.5, 0, +0.5, +1.0, +1.5, and +2.0 millimeters respectively.

*P values <0.05 indicate statistically significant differences between laypersons and dental professionals in their proportional responses regarding perception of esthetics.

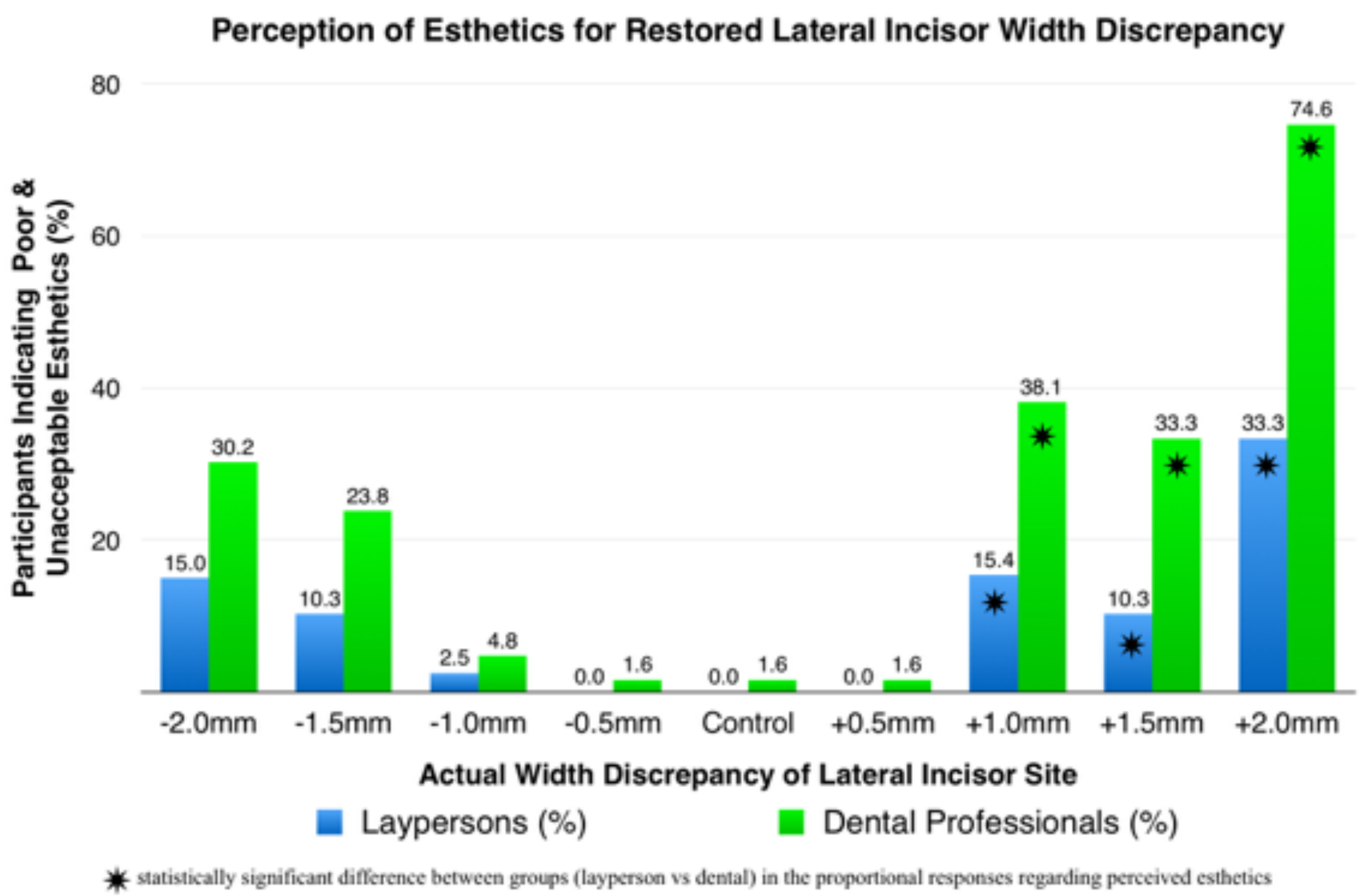

Figure 22 Percentage of laypersons and dental professionals indicating poor and unacceptable esthetics for digitally waxed lateral incisors having an actual width discrepancy of -2.0, -1.5, -1.0, -0.5, 0, +0.5, +1.0, +1.5, and +2.0 millimeters respectively.
*P values <0.05 indicate statistically significant differences between laypersons and dental professionals in their proportional responses regarding perception of esthetics.

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