[International Arab Journal of Dentistry](https://digitalcommons.aaru.edu.jo/iajd)

Volume 14 | Issue 2 Article 20

2023

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REVIEW ARTICLE / *REVUE DE LITTÉRATURE*

Dental Technology / *Technologie Dentaire*

DESIGNING OF CUSTOMIZED DEVICES IN ORTHODONTICS BY DIGITAL IMAGING AND CAD/FEM MODELING

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Abstract: In current decade, patient's demand of minimal orthodontic treatment have encouraged the introduction of appliance that will be lighter, improved profile and better esthetics with regard to conventional orthodontic treatment. Considering aesthetic treatment options, removable clear aligner treatment got popular among patients since it allows clinician to deliver comprehensive orthodontic treatment while maintaining comfort of patient. The aligners should exert an adequate force in order to shift the tooth to a desirable position. But, in recent times, the relation of applied force and aligner property (eg. thickness) is inadequately witnessed. This article focuses on a patient-focused framework has been formulated which depicts orthodontic movement of teeth with the help of aligners. Particularly, a finite element model is being formulated which optimizes the thickness of these aligners with respect to amount of force and moment system applied to a lower central incisor while tipping it bucco-lingually.

Keywords : computer assisted designing, orthodontic movement, orthodontic aligners, aligner thickness, finite element model

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Conflicts of interest:
The authors declare no conflicts of interest.

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CONCEPTION DE DISPOSITIFS PERSONNALISÉS EN ORTHODONTIE PAR IMAGERIE NUMÉRIQUE ET MODÉLISATION CAD/FEM

Résumé : Au cours de la décennie actuelle, une demande plus accrue de nos patients pour un traitement orthodontique minimal a encouragé l'introduction d'appareils plus légers et une meilleure esthétique par rapport au traitement orthodontique conventionnel. Compte tenu des options de traitement esthétique, le traitement par aligneurs transparents amovibles est devenu populaire auprès des patients puisqu'il permet au clinicien de faire un traitement orthodontique complet tout en préservant le confort du patient. Les aligneurs doivent exercer une force adéquate pour déplacer la dent dans la position souhaitée. Mais, ces derniers temps, la relation entre la force appliquée et la propriété de l'aligneur (par exemple l'épaisseur) n'est pas suffisamment observée. Cet article décrit le mouvement orthodontique des dents à l'aide d'aligneurs. En particulier, un modèle d'éléments finis est en cours de formulation, qui optimise l'épaisseur de ces aligneurs, dépendamment de la quantité de force et le système de moment appliqué à une incisive centrale inférieure, tout en l'inclinant bucco-lingualement.

Mots clés: conception assistée par ordinateur, mouvement orthodontique, aligneurs orthodontiques, épaisseur des aligneurs, modèle par éléments finis

Introduction

To establish the proper occlusion with the optimum functional and cosmetic aspects, orthodontic procedures are carried out. Using mechanical movements to reposition teeth into their precise positions inside the dental arches can correct uneven bites. The need for adult orthodontic treatment has increased, which has hastened the development of attractive alternatives to traditional fixed devices. Because of this, transparent teeth correction systems are being used more frequently for minimally invasive procedures. Particularly, procedures involving transparent, removable thermoplastic appliances (aligners) are becoming more popular. This technique includes a series containing translucent thermoplastic thermoformed templates that are consecutively worn by the patient [1]. This predetermined geometric mismatch between the shape of the aligner and the dentition geometry produces an orthodontic 3-dimensional force-moment system over every tooth. Computer-aided design (CAD) techniques and virtual 3D models of patients' dentition are used to diagnose this issue. This technique consists of a series of translucent thermoplastic thermoformed templates that are consecutively worn by these patients [2]. Each template is only programmed to carry out a small portion of entire tooth movements that corresponds to a new needed tooth positioning. So, from this original anatomical geometry to the target tooth position, a comprehensive treatment comprises the set including templates with different shapes [3]. For predicting and regulating tooth movements, it is essential to be able to simulate and recognize suitable moment-to-force ratios. Since the 1970s, dentistry has extensively used Finite Element Analysis (FEA), the most popular method for assessing the efficacy of dental equipment. The goal is to create a patient-specific framework that would enable a tailored simulation of orthodontic tooth motions using thermoplastic aligners. In order to build optimized appliances that result in more effective orthodontic treatments, a Finite Element (FE) model is developed. Even if using aligners to treat malocclusion disorders is increasingly effective. There have been few attempts to create FE models that describe how the aligner behaves when providing forces. Since there is not any particular point of force application, tooth motions with aligners cause more complications than fixed appliances. The clinical outcome is undoubtedly influenced by a number of factors, including tooth architecture, the material qualities of the aligner, the degree of mal-alignment between the aligner and dentition geometries, and slippage motions between the teeth. The thickness of the aligner in particular has been shown to have a significant impact on the amount of force generated by the appliance. The effects of the non-uniform thickness of aligners on quantity and quality of force applied on one central incisor while tipping using the constructed FE model. To provide a loading scenario, aligner surfaces are introduced. To maximize orthodontic treatment's success and prevent patient discomfort, this work has specifically looked into the influence of the aligner's thickness and form [4].

Methodology

Computer-aided scans and digital imaging techniques have been used to rebuild the anatomical geometry of the patient as well as the shape of the aligner. For example, dental anatomies, including the morphologies of the crown and root, are obtained using data from multiple sources. Orthodontic devices can be used to move teeth in an ideal way because they are made with consideration for both tooth geometry and crown geometry. Due to this, precise root geometries that were acquired from quick as well as accurate segmenting of Cone Beam Computed Tomography (CBCT) results are combined with approximations of accurate crown geometry that were obtained from high-precision optically scanned data. This aligner geometry was modeled using a CAD tool to produce the layer that nearly fits the surfaces of the tooth crown, except for the region corresponding to the tooth that needs to be relocated. A perforation between the crown and this area can be seen. Utilizing technologies from open-source software for medical picture processing, the jawbone's three dimensional model was created. By making a segment of the volumetric data, a triangular mesh of this surface depicting the bone shape has been created. CBCT data setting with a particular level of grey intensity [5].

Creating a Patient Anatomical Model

Utilizing data from CBCT scans and optical scans of relevant dental plaster cast, an anatomical model of the patient, containing alveolar bone, tooth, and periodontal ligament is made. The entire geometry of every individual tooth, as well as its relative spatial arrangements inside the jawbone, are obtained using the CBCT scan. This plaster model made from the patient's oral cavity imprint has been acquired using this optical scanner based on the coded structured light method. With the aid of optical scanning, a precise digital model made up of dental crowns is intended to be recreated. The full and individual tooth geometries, as well as the jawbone structure, are all recreated using CBCT volumetric data. One stack of slices representing a cross section through the volumetric region of the maxillofacial region is produced by a CBCT scan. A series of Digital Imaging and Communications in Medicine (DICOM) images are used for storing CBCT data. A 2D matrix of grey intensity values constitutes an imaging slice. Eight spots where the tooth axis (transverse slice) intersects the confidential interval (Ci) contours serve as a control point for computing the parametric B-spline curve of degree two. A hundred points were evaluated on a B-spline curve for each slice to create the point cloud that represents the general form of the tooth. The reader can consult for additional information [5].

Complete Tooth Geometric by CBCT Scanning

As tooth root areas can't be easily isolated from surrounding bone, reconstructing the individual tooth anatomy is not as simple. Focusing exclusively on the pixel's grey-intensity values. The majority of methods now in use are based on segmentation techniques that involve slices, which involve processing hundreds of slices digitally. Reconstructing three-dimensional geometry requires the use of hence leading to lengthy processes. That is DICOM images are processed using paper, this approach outlined during the processing of multiple plane reformation images, which is acquired for every tooth focusing anatomical considerations, is the basis of this procedure. The target tooth contours are much more visible in the reformation photos, and these contours will then be retrieved to automatically reconstruct the overall three-dimensional tooth shape using a B-spline representation [5]. Four reference planar sections are essentially automatically retrieved as passing from the tooth axis and orientated along the buccolingual direction, mesiodistal direction, and two directions arranged at 45 degrees about these 2 significant clinical views. These reference segments are utilized to interactively trace four alternative 2D tooth contours (Ci). Utilizing the four contours, automatic extraction, and B-spline curvature. Each parallel slice to the point clouds about the inferior arch's incisor, canine, and premolar teeth were employed in this investigation. The corresponding StL models were created by tessellating the corresponding point clouds [5]. The main advantage of this technology is the ability to interactively contour a few key pictures made from the entire CBCT data set, which results in accurate estimations of individual tooth roots [5]. Comparing the processing time to the normal, time-consuming slice-by-slice procedures typically suggested in medical imaging software. However, it cannot be said that the accuracy of the crown geometries, particularly for multi-cusped shapes, is sufficient to model orthodontic procedures based on the use of specialized appliances [5].

Crown Geometric by Optical Scanning

The plaster patient model was acquired using an optical scanner based on a coded structured light technique. Digital mouth reconstruction made up of gingival tissue and crown forms is created. Using a semi-automated process that takes advantage of the curvature of this digital mouth model, the overall surface is then divided into several sections that reflect the various crown geometries and the gingiva [6].

Multi-Source Data Fusion

To produce multibody dental models, multi-source data from optical and tomographic scans for each tooth must be combined. The segmented crown geometries from CBCT data scans are lined up with the corresponding crown surfaces gained by optical scanning. By manually choosing at least three shared points, meshes from these 2 sets of data are roughly aligned to one common reference frame. The initial alignment is then improved upon. Conducted using an iterative closest point (ICP)-based fine registration process. Following the analysis of DICOM images, the crown geometries are subsequently eliminated using a disc vertex selection technique. On the CBCT mesh, each vertex of this optic crown corresponds to a point. This point, which designates a sphere's center, is used to choose which points from the CBCT mesh should be removed. After that, a Poisson surface reconstruction method is used to create the final tooth models. This enables the most accurate portrayal of dental crowns to be used in fully closed models [6].

Periodontal Ligament Modeling

Since the typical slice thickness is the Design of Customized Orthodontic Devices by Digital Imaging and CAD/FEM Modeling, periodontal ligament (PDL) geometries are difficult to perceive and rebuild. Equivalent to or larger than the ligament space (about 0.2 mm). Due to this, in this work, the PDL has been reconstructed for each tooth by identifying the location where the tooth and bone models meet and adding a 0.2 mm thick shell. This PDL volume is calculated by subtracting the volume shell from the alveolar bone. The PDL solid models attained [7].

Orthodontic Aligner Modelling Process

By creating a layer that is entirely congruent with the surface of the tooth crown, the geometry of the aligner was developed. To generate a distinct layer, the individual teeth are first linked, root geometries are eliminated, and undercut volumes are manually removed. To build a volume that is 0.5 mm thick, the layer is thickened. To represent the interior shape of the aligner, the combined tooth geometries are then subtracted from the volume and the outermost surface of the remaining geometry is eliminated. This operation is done to provide a perfect fit between the appliance and the mating surfaces of the tooth crowns. The thermoplastic material disk's average thickness, which was 0.75 mm thick before the thermoforming process, serves as the basis for the aligner's intended uniform thickness of 0.7 mm. The inner form of the aligner has been thickened by 0.7 mm in the direction corresponding to the surface to produce a shell. The generally modeled geometries were employed to build the FE model. The effectiveness of the orthodontic treatment has been tested in this work using a different modeling method to examine the impact of non uniform aligner thickness values. The concept is to alter the appliance geometry by modifying the width of the appliance in locations with significant deformation and thinning the model in parts with low deformation. By doing so, it would be possible to maximize the forces applied to each tooth in the arch. The aligner displacement values are employed in particular to precisely alter the aligner's thickness [8].

Generation of the Finite Element Method (FEM)

In Ansys® 14, the various bodies were imported. Solid 10-node tetrahedrons were used to model each body. For each simulation, there were around 134000 elements and 226000 nodes. Displays the mesh models for the simulation run with a constant aligner thickness of 0.7 mm [9].

Properties of materials

Each body was given a mechanical model of linear elasticity. Furthermore, it was assumed that both teeth and bone were formed of a homogenous substance, without distinction between the enamel, pulp, and dentin of the tooth, and cortical and cancellous bone. As demonstrated in earlier experiments, this simplification has no impact on the simulation results. Numerous biomechanical models that simulate the characteristics of the tooth ligament are found in technical literature. Due to the ligament's diminutive size (approximately 0.2 mm in thickness), studying its in-vivo functioning is not an easy undertaking [10]. Due to this, experimental investigations have been used to determine the mechanical characteristics of the periodontal ligament in the maximum scientific literature, leading to the development of five different models: linear elastic, bilinear elastic, viscoelastic, hyperelastic, and multiphase. This PDL's complex non linear response does not have to be addressed when doing an investigation of the initial orthodontic reaction [11]. The manufacturer's datasheet can be used to determine the mechanical characteristics of the polyethylene terephthalate glycol-modified (PETG) disc intended to make the thermoplastic aligners. Linear elastic has been used to approximate its mechanical characteristics [11]

Loading and Boundary Condition

A mandibular central incisor's bucco-lingual tipping was modeled. Penetration between the aligner and the target tooth produced an initial load setting for the FE analysis. Since the aligner is modeled on the surfaces of these teeth, the first model doesn't show any penetration between the teeth and the aligner. To initiate initial penetration, the tooth is to be rotated around its Center of Resistance. The technique suggested was used to establish the location of the tooth's Center of Resistance. The reference axes are established with an occlusal plane in mind. All directions of bone extremities were fixed. To simulate touch, an extended Lagrangian formulation was employed. Bone and PDL as well as PDL and teeth were both regarded to have bonded contact surfaces. It is expected that there is adequate adhesion between the contact surfaces, with no sliding or separation between the corresponding nodes. For the optimum accuracy-to-computational time ratio, the aligner-teeth contract was set to be frictionless, with a maximum allowable penetration of 0.01 mm. An unintended initial penetration between the aligner and the non-target teeth might happen as a result of the meshing process. To eliminate all of the unwanted initial contacts, the "adapt to touch" option was employed for those contact couples [12-14].

Analysis Setting

The impact of the aligner's thickness on orthodontic movement, various situations were simulated 0.7 mm uniform thickness; 0.6 mm uniform thickness; and 0.62 mm non-uniform thickness attained. The Center of Resistance computed the force and moment systems that the aligner ultimately applied to the target teeth in every simulation. Using a Workstation with an Intel Xeon CPU E3-1245 v3@3.40 GHz and 16 GB RAM, the computation time for each simulation was roughly 2 hours [8].

Outcome

Orthodontic movement is mostly caused by the bone remodeling process, which is directly impacted by PDL stress levels [15]. From 0.6 mm to 0.7 mm thickness of the aligner, the moment imparted to the tooth rose by 50% [16]. While the non-uniform aligner produced a moment that was 173 percent and 75% higher than the 0.6 mm and 0.7 mm, respectively. The stress readings in the PDL also followed a similar trend [17,18]. In line with an anticipated buccolingual movement of the tooth, each of these several situations displayed a positive stress value on the higher section of the anterior region and a negative stress value on the posterior. For a non-uniform aligner, the maximum stress value was approximately twice as high as the displacement on the target tooth that occurred in various configurations [10]. The force exerted by thick material is greater than thinner material [19]. Thus Clear aligners provide an aesthetically compatible treatment option in orthodontics [20,21] but root resorption is still a major risk factor associated with this treatment [22].

Discussion

Orthodontics provides various elements for the correction of, malocclusion with the help of customized orthodontics devices for the aesthetic concerns of the patient

[23]. Thus to study the mechanism of orthodontic appliances computer modeling and finite element analysis is important. The components of the tested object must be completely comprehended to operate such simulations efficiently. Orthodontics biomechanics is theoretically analyzed by force balance. [24]. As we made an effort to replicate the oral environment as accurately as possible, elastomeric force degradation has an impact on the force system [25]. The objective of article is to maintain the PDL structures, biological variation, alveolar bone geometries, crown anatomical geometries, and root anatomical geometries. Thus to maintain the final design of orthodontic appliances (aligners) [26]. The thickness of aligners should be uniform to maintain patient comfort. Appliance thickness should thick so that force applied by appliance should be efficient and greater and oral environment condition should be moderate for the aligners [27]. Finite element analysis provide the non-uniform thickness aligners that affect the tipping of lower arch incisors and CBCT patient data is collected and multiple source is combined to analyze and produce clear aligners structure [28]. The resistance should be in center of the crown for the movement of crown with aligners for the aesthetic alignment of teeth [29]. CBCT data scanning is done to see jawbone design and individual tooth structure design and optical scanning of patients cast to seen the gingival tissue and crown structure design and after designs are structured through the individual tooth structure design form the root anatomical structure geometries, gingival tissue and crown structure design forms the crown anatomical structure geometries. All the data is collected and matching of the data collection is done and formation of the final tooth structure is designed. Finite element model optimized structure of clear aligners [30].

Conclusion

Aligners made of thermoformed plastic have shown problems when applying complex force systems. Particularly, central incisor extrusions, canine and premolar rotation, and inclination are achieved in orthodontic practice by the use of composite elements as attachments, glued to the surface of the crowns, or divots and power ridges to improve mechanical efficacy. Since this aligner material alone imparts the force system, the aligner thickness represents an extra crucial component that must be tuned. A minimum value for aligner thickness would reduce patient discomfort. In contrast to thin materials, thick appliances deliver greater forces. For every stage of orthodontic treatment, aligners are typically created using a vacuum thermoforming process applied to 3D physical molds of teeth created via RP methods. Every prototyped mold is covered with a single thermoplastic polymer resin layer that is roughly 0.75 mm thick before being trimmed to extract the desired configuration. This is why the aligners are often designed with a consistent thickness. By utilizing FE analysis, it has been determined in this work how a non-uniform aligner's thickness affects the tipping of the mandibular central incisor. According to preliminary findings, a force system that precisely modulates the aligner's thickness to change stiffness can send a force to the central incisor that is more effective. A greater magnitude of desirable moments and improved movement qualities were produced by the non-uniform device. These results demand that the manufacturing process for aligners be taken into account. At the moment, thermoforming procedures-which only offer aligners of constant thickness-strictly restrict the typical production processes. The aligner should be directly manufactured using a different technique. For example, layer-by-layer printing of single or several polymeric materials or milling by CNC (Computerized Numerical Control) machines would enable the production of irregular, thin walled polymeric orthodontic aligners. A large spring back, high energy, resistance to harsh oral tissues, biocompatible properties, and low surface roughness by mating surfaces are, nonetheless, the key qualities of an aligner. When selecting an alternate production process, these characteristics should be given careful consideration. This topic undoubtedly provides a difficult task. In addition to the thickness of the aligners, the mechanical qualities of the thermoplastic materials also play a major role in making a successful orthodontic treatment. The real mechanical qualities may vary between the intraoral environment and room temperature depending on temperature, humidity, and the formation processes. To describe the mechanical properties of aligners in practical settings, certain experimental studies are now being conducted by replicating an intraoral environment.

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