3D Virtual Model Simulation: Applications for Dento-Facial Deformities

Yassir Sabri[1], Zaoui Fatima[2], Boudi El Mostapha[3] and Benyahia Hicham[2]
[1]*PhD Student CEDOC SVS, Faculty of Dentistry, Mohammed V University in Rabat, Morocco*
[2]*Department of Orthodontics, Faculty of Dentistry, Mohammed V University in Rabat, Morocco*
[3]*Department of Mechanical Engineering, Mohammadia School of Engineering, Mohammed V University in Rabat, Morocco*

Keywords: Biomechanical FEM Simulation, DICOM, 3D Modelling, Orthodontic Tooth Movement, Biomechanics.

Abstract: Nowadays, virtual treatment planning allows clinicians to create detailed, patient-specific workflows through digital simulations. This improves the accuracy of treatment plans and leads to an efficient, and patient-centric care. In dentistry, Computer-Aided Design and Computer-Aided Manufacturing CAD/CAM systems enable digital design and fabrication of a all kind of oral devices like surgical guides for implant placement, or orthodontic clear aligners. In the present paper, a 3D model will be created in order to be used to understand orthodontic loadings effects on tooth movement and adjacent structures. Material and method: Cranio-facial imaging data (Dicom) was used to creat a 3D model of a partial dento-alveolar model. All materials (teeth, PDL and alveolar bone) were considered having isotropic linear elastic properties. Results: the 3 D model will be used to realize a simulation by finite element method using more than 77158 second-order Lagrangian tetrahedral elements. Discussion & Conclusion: The application of 3D virtual model in the context of dento-facial deformities offers numerous advantages for diagnosis, treatment planning, and patient communication, clinicians may be able to develop more effective and mechanically sound treatments with the use of numerical simulation.

1 INTRODUCTION

In recent years, the integration of digital technologies in the medical field has revolutionized patient care. Advanced digital tools provide healthcare professionals with a powerful means to simulate and address various medical situations (J. S. Shinbane and L. A. Saxon, 2018), (P. Riutord-Sbert et al., 2023).

In dentistry, there are many applications based on digital technologies, in particular virtual treatment planning, meaning the ability for dental clinicians to create detailed, patient-specific workflows. This not only improves the accuracy of treatment plans but also allows for a more personalized approach, and for efficient, and patient-centric care (J. S. Shinbane and L. A. Saxon, 2018), ("Aplicación del metaverso como técnica de aprendizaje en el grado de odontología. Estudio preliminar"), (L. Camardella et al., 2016).

Digital radiography, including intraoral and extraoral X-rays in particular: Cone Beam Computed Tomography (CBCT), provides three-dimensional images of oral structures, enabling detailed assessment for treatment planning in areas like implant placement, oral surgery, and orthodontics (R. Urban et al., 2023), (H. W. Moon et al., 2020).

Computer-Aided Design and Computer-Aided Manufacturing CAD/CAM systems enable the digital design and fabrication of classical dental restorations such as crowns, bridges, and veneers, as well as a new array of oral devices like surgical guides for implant placement, or orthodontic clear aligners (A. Skorulska et al., 2021).

The application of 3D virtual model in the context of dento-facial deformities offers numerous advantages for diagnosis, treatment planning, and patient communication. Surgeons and orthodontists can use 3D virtual model for digital simulations based on High-resolution imaging providing detailed representations of teeth and craniofacial structures to create patient-specific treatment plans.

The aim of our study is to generate a dento-alveolar virtual model from acurate imaging data (Dicom).

Sabri, Y., Fatima, Z., El Mostapha, B. and Hicham, B.
3D Virtual Model Simulation: Applications for Dento-Facial Deformities.
DOI: 10.5220/0012866300003854

In *Proceedings of the 1st International e-Health Forum (IeHF 2023)*, pages 25-28
ISBN: 978-989-758-711-5

Figure 1: Different applications of digital technologies in *Dentistry.*

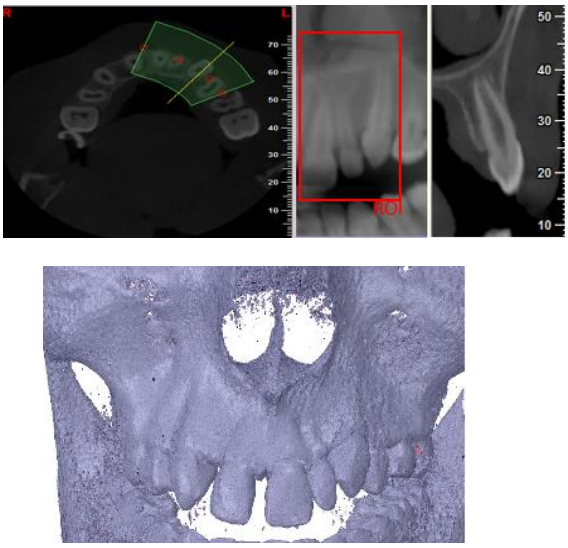

Figure 2: CT images captured in DICOM format and ROI.

2 MATERIAL AND METHODS

2.1 DICOM Data

A maxilla cone beam CT file (in DICOM format) was selected from imaging database of orthodontic department (CCTD CHIS Rabat), respecting several criteria: no previous orthodontic or orthopedic treatment histories, no craniofacial anomalies, no previously reported or observed dental treatment or anatomical defects on the canine incisors segment.

Table 1: Mechanical Proprieties of Materials.

Anatomic element	Young's module (MPa)	Poisson's coefficient	Thickness (mm)
Bone	2000	0.30	
Periodontal ligament	0,68	048	0.2
Tooth	20000	0.15	
Material of bracket	200000	0.3	

The conebeam selected belong to a 13-year-old girl, who was treated for maxillary bilateral second premolars impaction (Conebeam equipment: resolution of approximately 150-300m/pixel. Myray Hyperion X9 3d, NNT viewer was utilised to process the CT images).

2.2 3D Modelling

Region of interest (ROI): for this preliminary study, we focused on left maxillary canine and incisors, a segment of three teeth: 2.1., 2.2., 2.3 as shown in fig.1. It's a simple partial model to test orthodontic load on a single tooth (2.2) and reaction effects on adjacent ones.

The CT images were segmented on invesalus software*, by defining thresholds separately for both teeth and bone based on their respective Hounsfield unit (HU). 2 masks (STL format) were then created and further processed on Catia v5 (*), to create the 3D solid model.

The process consists of several stages: including surface refinement, mask filling, PDL modelling by virtual reconstruction from the external radicular surface of teeth, and orthodontic brackets design.

3 RESULTS

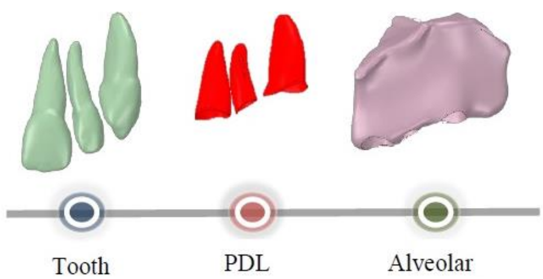

Figure 3: Decomposition of study system.

The 3D model will be used to realize a simulation by finite element method using more than 77158 second-order Lagrangian tetrahedral elements.

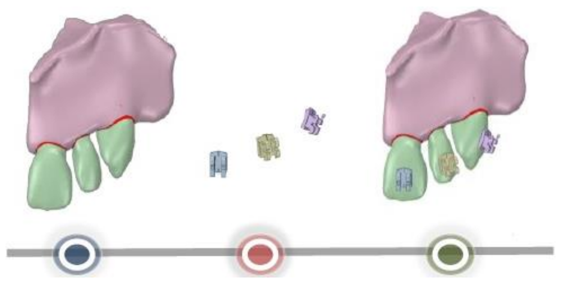

Figure 4: Study model with bracket.

We will apply a force of 2N to study dentofacial deformities.

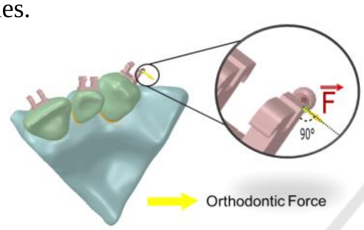

Figure 5: Preliminary study: distal orthodontic force on canine bracket.

4 CONCLUSIONS

The applications of 3D virtual model in order to realize FE simulation will help us to study dento-facial deformities for advancement in treatment planning and patient care.

As technology continues to advance, the potential for virtual simulations in medical and dental treatment remains limitless, promising a future of healthcare where innovation and precision converge for the benefit of patients and practitioners.

REFERENCES

J. S. Shinbane and L. A. Saxon, "Virtual medicine: Utilization of the advanced cardiac imaging patient avatar for procedural planning and facilitation," *Journal of Cardiovascular Computed Tomography*, vol. 12, no. 1. Elsevier Inc., pp. 16–27, Jan. 01, 2018. doi: 10.1016/j.jcct.2017.11.004.

P. Riutord-Sbert *et al.*, "Aplicación del metaverso como técnica de aprendizaje en el grado de odontología. Estudio preliminar," *Academic Journal*, 2023, doi: 10.3306/AJHS.2023.38.02.43.

"Aplicación del metaverso como técnica de aprendizaje en el grado de odontología. Estudio preliminar".

L. Camardella, E. Rothier, O. Vilella, E. Ongkosuwito, and K. Breuning, "Virtual setup: application in orthodontic practice.," *Journal of Orofacial Orthopedics/Fortschritte der Kieferorthopadie*, vol. 77, no. 6, 2016.

(R. R. Urban *et al.*, "AI-Assisted CBCT Data Management in Modern Dental Practice: Benefits, Limitations and Innovations," *Electronics (Switzerland)*, vol. 12, no. 7. MDPI, Apr. 01, 2023. doi: 10.3390/electronics12071710.

H. W. Moon *et al.*, "Molar inclination and surrounding alveolar bone change relative to the design of bone-borne maxillary expanders: A CBCT study," *Angle Orthodontist*, vol. 90, no. 1, pp. 13–22, 2020, doi: 10.2319/050619-316.1.

A. Skorulska, P. Piszko, Z. Rybak, M. Szymonowicz, and M. Dobrzyński, "Review on polymer, ceramic and composite materials for cad/cam indirect restorations in dentistry—application, mechanical characteristics and comparison," *Materials*, vol. 14, no. 7. MDPI AG, Apr. 01, 2021. doi: 10.3390/ma14071592.

A. Geramy, K. Tanne, M. Moradi, H. Golshahi, and Y. Farajzadeh Jalali, "Finite element analysis of the convergence of the centers of resistance and rotation in extreme moment-to-force ratios," *Int Orthod*, vol. 14, no. 2, pp. 161–170, 2016, doi: 10.1016/j.ortho.2016.04.001.

P. M. Cattaneo, M. Dalstra, and B. Melsen, "The finite element method: A tool to study orthodontic tooth movement," *J Dent Res*, vol. 84, no. 5, pp. 428–433, 2005, doi: 10.1177/154405910508400506.

Y. Qian, Y. Fan, Z. Liu, and M. Zhang, "Numerical simulation of tooth movement in a therapy period," *Clinical Biomechanics*, vol. 23, no. SUPLL.1, pp. 48–52, 2008, doi: 10.1016/j.clinbiomech.2007.08.023.

A. Bouton, Y. Simon, F. Goussard, L. Teresi, and V. Sansalone, "New finite element study protocol: Clinical simulation of orthodontic tooth movement," *Int Orthod*, vol. 15, no. 2, pp. 165–179, 2017, doi: 10.1016/j.ortho.2017.03.001.

W. Ryniewicz *et al.*, "Three-dimensional finite element simulation of intrusion of the maxillary central incisor," *Biocybern Biomed Eng*, vol. 36, no. 2, pp. 385–390, 2016, doi: 10.1016/j.bbe.2016.02.003.

J. Chen, W. Li, M. V. Swain, M. Ali Darendeliler, and Q. Li, "A periodontal ligament driven remodeling algorithm for orthodontic tooth movement," *J Biomech*, vol. 47, no. 7, pp. 1689–1695, 2014, doi: 10.1016/j.jbiomech.2014.02.030.

A. Manmadhachary, Y. Ravi Kumar, and L. Krishnanand, "Improve the accuracy, surface smoothing and material adaption in STL file for RP medical models," *J Manuf Process*, vol. 21, pp. 46–55, 2016, doi: 10.1016/j.jmapro.2015.11.006.

J. H. Marangalou, F. Ghalichi, and B. Mirzakouchaki, "Numerical simulation of orthodontic bone remodeling," *Orthodontic Waves*, vol. 68, no. 2, pp. 64–71, 2009, doi: 10.1016/j.odw.2008.12.002.

J. P. Gomez, F. M. Peña, V. Martínez, D. C. Giraldo, and C. I. Cardona, “Initial force systems during bodily tooth movement with plastic aligners and composite attachments: A three-dimensional finite element analysis,” *Angle Orthodontist*, vol. 85, no. 3, pp. 454–460, 2015, doi: 10.2319/050714-330.1.

A. Hohmann *et al.*, “Periodontal ligament hydrostatic pressure with areas of root resorption after application of a continuous torque moment: A study using identical extracted maxillary human premolars,” *Angle Orthodontist*, vol. 77, no. 4, pp. 653–659, 2007, doi: 10.2319/060806-234.

A. M. Schwarz, “Tissue changes incidental to orthodontic tooth movement,” *Kokubyo-Gakkai-Zasshi*, vol. 6, no. 3, pp. 226–228, 2017, doi: 10.5357/koubyou1927.6.3_226.