open access scientific journal

Volume 26 N º 01 - **2023** | **Special Edition**

Brazilian Dental Science

25th Jubilee

Source:macrovector/Freepik

unesp

UNIVERSIDADE ESTADUAL PAULISTA
"JÚLIO DE MESQUITA FILHO"
Instituto de Ciência e Tecnologia
Campus de São José dos Campos

Brazilian Dental Science
unesp
UNIVERSIDADE ESTADUAL PAULISTA
"JÚLIO DE MESQUITA FILHO"
Instituto de Ciência e Tecnologia
Campus de São José dos Campos

ORIGINAL ARTICLE
DOI: https://doi.org/10.4322/bds.2023.e3485

Stress distribution in lower second molar mesialization using mini-implants: a pilot study using 3D finite element analysis

Distribuição de tensões na mesialização do segundo molar inferior usando mini-implantes: um estudo piloto usando análise de elementos finitos 3D

João Maurício Ferraz da SILVA[1], **Juliana da Costa LISBOA**[1], **Fernanda Zapater PIERRE**[1], **Rodrigo Máximo de ARAÚJO**[1], **Cleidiel Aparecido Araujo LEMOS**[2], **Ronaldo Silva CRUZ**[3], **Fellippo Ramos VERRI**[4]

1 – Universidade Estadual Paulista "Júlio de Mesquita Filho", Instituto de Ciência e Tecnologia, Departamento de Materiais Odontológicos e Prótese. São José dos Campos, Brazil.
2 – Universidade Federal de Juiz de Fora, Odontology Department. Governador Valadares, Brazil.
3 – Universidade Estadual Paulista "Júlio de Mesquita Filho", Dentistry Science Program on the Dental Materials and Prosthodontics Department of the Dentistry School. Araçatuba, Brazil.
4 – Universidade Estadual Paulista "Júlio de Mesquita Filho", Dental Materials and Prosthodontics Department of the Dentistry School. Araçatuba, Brazil.

How to cite: Silva JMF, Lisboa JC, Pierre FZ, Araújo RM, Lemos CAA, Cruz RS, et al. Stress distribution in lower second molar mesialization using mini-implants: a pilot study using 3D finite element analysis. Braz. Dent. Sci. 2023;26(1):e3485. https://doi.org/10.4322/bds.2023.e3485

ABSTRACT

Objective: to analyze the stress distribution in a 3D model that simulates second molar mesialization using two different types of mini-implants. **Material and Methods:** a mandible bone model was obtained by recomposing a computed tomography performed by a software program. The cortical and trabecular bone, a lower second molar, periodontal ligament, orthodontic tube, resin cement and the mini-implants were designed and modeled using the Rhinoceros 4.0 software program. The characteristics of self-drilling orthodontic mini-implants were: one with 7 mm length, 1 mm transmucosal neck section and 1.6 mm diameter and another with 5 mm length and 1.5 mm diameter. A total of 235.161 and 224.505 elements were used for the mesh. These models were inserted into the bone block and then subjected to loads of 200 cN (centinewton). The results were calculated and analyzed by the Ansys 17.0 software program for qualitative verification through displacement and maximum principal stress maps. **Results:** it was possible to observe that the periodontal ligament presented low displacement and stress values. However, the physiological values presented are among those capable to provide orthodontic movement, with compression and tensile area visualization staggered between 0.1 and -0.1 MPa (megapascal). **Conclusion:** within the limitations of the study, the mini-implants tested showed similar results where the load on the tooth allowed dental displacement (molar mesialization), with a tendency to rotate it, theoretically allowing the second molar to take the location of the first molar.

KEYWORDS

Finite element analysis; Orthodontic anchorage procedures; Fixed orthodontic appliances; Mini dental implants; Tooth dislocation.

RESUMO

Objetivo: analisar a distribuição de tensões em um modelo 3D que simula a mesialização do segundo molar usando dois tipos diferentes de mini-implantes. **Material e Métodos:** um modelo de osso mandibular foi obtido por recomposição de uma tomografia computadorizada realizada por um software. O osso cortical e trabecular, um segundo molar inferior, ligamento periodontal, tubo ortodôntico, cimento resinoso e os mini-implantes foram projetados e modelados no software Rhinoceros 4.0. As características dos mini-implantes ortodônticos auto perfurantes foram: um com 7 mm de comprimento, 1 mm de secção transmucosa e 1,6 mm de diâmetro e outro com 5 mm de comprimento e 1,5 mm de diâmetro. Para a malha, foram utilizados 235.161 e 224.505 elementos. Esses modelos foram inseridos no bloco ósseo e então submetidos a cargas de 200 cN (centinewton). Os resultados foram calculados e analisados pelo software Ansys 17.0 para verificação qualitativa por meio de mapas de deslocamento e tensões máximas principais. **Resultados:** foi possível observar que o ligamento periodontal apresentou baixos valores de deslocamento e tensões. Porém, os valores fisiológicos apresentados são capazes de proporcionar movimentação ortodôntica, com visualização da área de compressão e tração escalonada entre 0,1 e -0,1 MPa (megapascal). **Conclusão:** dentro das limitações do estudo, os mini-implantes testados apresentaram resultados semelhantes onde a carga sobre o dente permitiu o deslocamento dentário (mesialização do molar), com tendência a girá-lo, permitindo teoricamente que o segundo molar ocupe do lugar do primeiro molar.

PALAVRAS-CHAVE

Análise de elementos finitos; Procedimentos de ancoragem ortodôntica; Aparelhos ortodônticos fixos; Mini implantes dentários; Deslocamento dentário.

INTRODUCTION

Patients who have malocclusions due to tooth loss are commonplace in dental offices. According to data in the literature, the first permanent lower molar is the most affected, as it erupts in the oral cavity in childhood around 6 years of age [1]. Thus, it is often mistaken for a deciduous tooth, and if there is any carelessness in the child's brushing or diet, there may be an accumulation of biofilm, progress to caries, and depending on the state of the disease, could end up causing the loss of element [2].

Dental surgeons are frequently questioned about treatment alternatives for rehabilitation or space closure. Multidisciplinary treatments in these cases are generally a good rehabilitative approach [3]. Therefore, the dental surgeon must always pay attention to the clinical examination and anamnesis, in addition to the general health status of the patient to design a good treatment plan, be predictable and avoid as many complications as possible [4,5]. Some important aspects in the case of tooth loss should be analyzed, such as the presence of malocclusion, bone and root integrity, treatment time and geometry of dental positioning to conclude if space closure would guarantee finalization in agreement with experts' ideals [6].

Molar mesialization is an effective resource in orthodontic mechanics and benefits patients by reducing the need for replacing missing teeth by prostheses. Not including orthodontic treatment in treatment possibilities will always generate a high number of extractions or implant indications which could be avoided. However, movement demands longer treatment time, mechanics induce some side effects, and the factors involved in alveolar bone atrophic quality should be analyzed and considered in order to avoid adverse effects [6].

Lower second molar mesial movement usually results in incisor lingual inclination and mesial inclination when performed in a conventional manner [6]. The anchorage, which results from the use of the mini-implant, provides an appropriate force vector targeting, generating dental movement with radicular parallelism. In other words, the force applied is free of inclination, eliminating the need for inclusion of other teeth in mechanics. Moreover, it eliminates any possibility of unwanted movement of previous teeth [7].

The rising use of implants as temporary anchoring has been systematically reported in the scientific literature over the last decades [8]. It introduces the possibility of dental movement with increased predictability of results [9-11].

Mini-implants became widely used due to the considerable clinical efficiency and accessibility that they provide (among others factors). Diameters range vary from 1.2 to 2.0 mm (millimeters) and length from 5 to 12 mm for self-drilling or self-tapping designs, and 0 to 3 mm for transmucosal neck [12]. In addition, they present high fracture resistance and low propensity to osseointegration due to the grade V titanium alloy (Ti-6AI-4V) which they are made from [12]. The mini orthodontic implant was also considered an option to obtain maximum anchorage during anchorage loss [13].

The mechanism of action and reaction of mini-implants in molar mesialization can be biomechanically studied through the finite element analysis (FEA) method. FEA consists of a mathematical method through a large system which is subdivided into elements, retaining their original properties. It transforms a complex problem into a sum of several simple problems, solving the whole set [13,14]. Therefore, it is possible to model mathematically complex structures with irregular geometries of natural and artificial tissues, such as teeth, bones, and biomaterials. Furthermore, it is possible to apply a system of forces, with it being possible to promote displacement and stress information about the analyzed object [13,15]. With the help of patient-specific simulation, orthodontists can predict the outcome precisely, and lower the stress by adjusting the force or changing the appliance if it is higher than expected [13].

The purpose of this study was to analyze the displacement and stress distribution, mainly in the cortical bone tissue and periodontal membrane, in using lower molar mesialization with different types of mini orthodontic implants as anchorage through finite element analysis (FEA).

MATERIAL AND METHODS

A three-dimensional model was produced in the Rhinoceros 4.0 software program (Seattle, WA, USA) containing: a block of left mandibular posterior region, a lower second molar, periodontal ligament, a single Roth prescription orthodontic tube with hook (REF 20.11.222 - Morelli Ortodontia, Sorocaba, SP, Brazil) added to a power-arm, resin cement, and a 7 mm long self-drilling mini-implant, with 1 mm transmucosal neck section and 1.6 mm diameter (Mini-implant for Absolute Anchorage - Straumann / Neodent, Curitiba, PR, Brazil) for the first simulation; and a mini-implant of 5 mm length and 1.5 mm diameter (Mini-implant for absolute anchorage - Titanium Fix, São José dos Campos, SP, Brazil) for the second simulation, always placed horizontally, mesially to the molar tooth at a distance of 10 mm (Figure 1).

The bone block was obtained by recomposing a computed tomography performed by the InVesalius software program (CenPRA, Campinas, SP, Brazil) as in a previous study [14-16]. This program uses *stl* format to generate the solid body of the analyzed region and simplifications before exporting were made to try to smoothen the external surface when possible. The trabecular bone simulation was performed by bone block external surface offset. Thus, the cortical bone of 2 mm thickness surrounded the trabecular bone, simulating the bone type II. This simulation was performed after exportation in the CAD Rhinoceros 4.0 software program (Seattle, WA, USA).

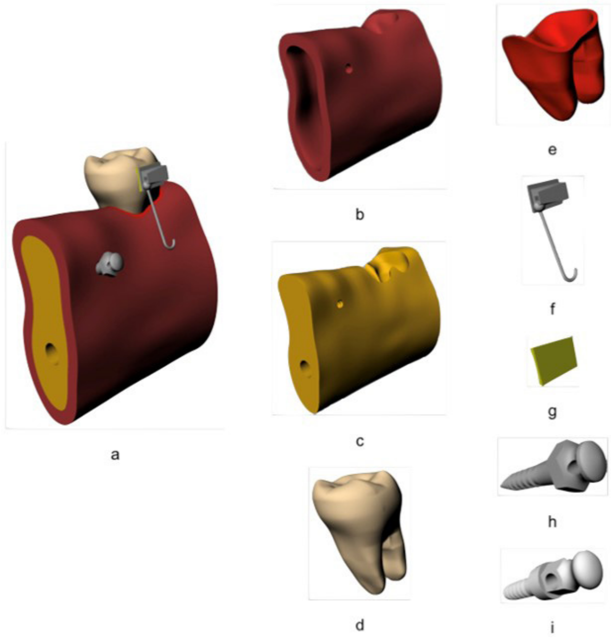

Figure 1 - 3-D modelling. Legend: a) general model; b) cortical bone; c) trabecular bone; d) tooth; e) periodontal ligament; f) orthodontic tube; g) resin cement; h) Neodent mini-implant; i) TitaniumFix mini-implant.

The mini-implants were installed as close as possible to the occlusal plane to decrease the intrusive vector in molar mesial, and consequently its inclination. They were designed from a profile photograph in high resolution and modeled by a revolution tool in the Rhinoceros 4.0 software program (Seattle, WA, USA), following a simplification methodology presented in a previous study [17]. The orthodontic tube design was equally simulated for the mini-implant.

The natural tooth design was performed by a profile drawing of an extracted natural molar tooth. Photography and measurements (using a digital caliper) of all its faces was taken in order to guide the drawing. Simplifications were performed to facilitate the computational processing, mainly smoothing surfaces to improve computer performance.

Next, the models were exported in STEP format to an analysis software program (Computer-Aided Engineering, ANSYS version 17.0, Ansys, Inc., Canonsburg, PA, USA). The meshes were created by CFD physical preference, using automatically mesh created by the program with target skewness of elements of 0.9, constituting the regions of interest (periodontal ligament and contact with cortical bone, mini-implant and contacts with trabecular and cortical bones), and refined when necessary. The models had 235.161 (Neodent) and 224.505 tetrahedron elements (TitaniumFix) (Figure 2).

The mechanical properties of the materials used in the study were obtained from previous research data and are shown in Table 1. All were simulated in a homogeneous, isotropic and linear behavior.

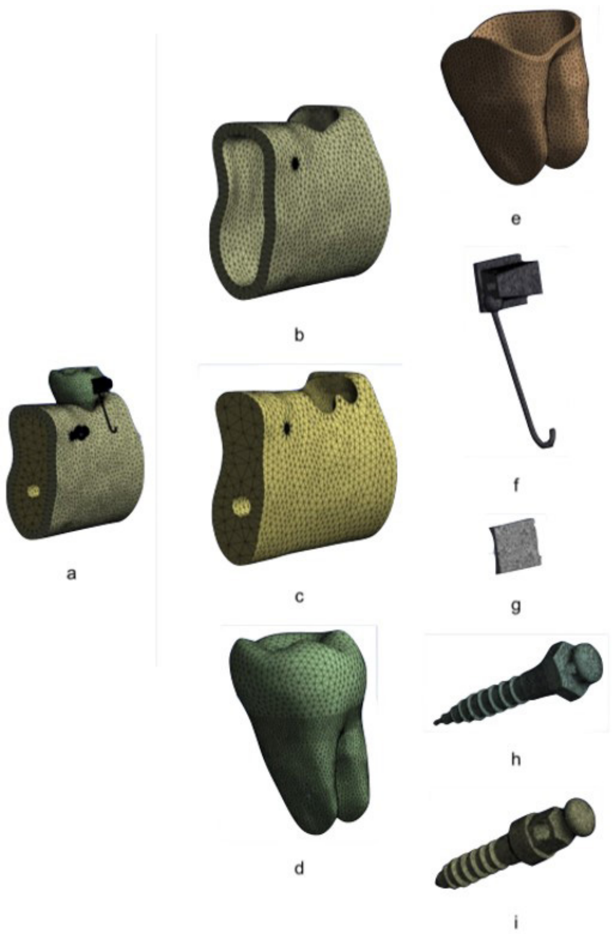

Figure 2 - Finite element meshes. Legend: a) general model; b) cortical bone; c) trabecular bone; d) tooth; e) periodontal ligament; f) orthodontic tube; g) resin cement; h) Neodent mini-implant; i) TitaniumFix mini-implant.

Table 1 - Mechanical properties of the materials used in the study

Material	Modulus of elasticity (MPa)	Poisson Coefficient
Cortical Bone [16,17]	13,700	0.3
Trabecular Bone [16,17]	1,370	0.3
Tooth [18]	20,000	0.3
Periodontal Ligament [16]	68.9	0.45
Stainless Steel [15,18]	210,000	0.3
Resin Cement [16]	7,000	0.3
Titanium [14,17,18]	110,000	0.3

The force application point was positioned near the center of molar resistance in order to make the tooth movement feasible, located approximately 1 mm apically to the furcation. Loads of 200 cN were applied in action-reaction pair, both in the implant and in the orthodontic device handle, in order to simulate orthodontic elastic in function. The model was fixed in mesial and distal faces, cortical surfaces and trabecular bones along the x, y and z axes, not allowing the model displacement, but granting the possibility of undergoing the simulated internal forces. The analyzes were performed by static structural linear mode, and displacement and maximum principal stress maps were plotted to visualize the results.

RESULTS

The displacement maps indicate movement tendency of the analyzed structures, in which 'mm' (millimeters) was the scale unit adopted. The maximum displacement values were approximately 1.2 mm for both models, always showing a greater movement tendency in the orthodontic device handle, near the force application region. The displacement values in the mini-implant anchorage region were close to 0.001 mm in both models. The periodontal ligament was individualized for qualitative analysis due to its importance.

It is possible to observe that the maps are quite similar regarding the periodontal ligament individualization, regardless of the implant used. Both show a slightly higher tendency to move to the mesial region (yellow area on maps), which is due to the force application direction (Figure 3).

Maximum principal stress qualitatively shows areas prone to compression (negative values) and an area prone to tensile stress (positive values), for which the unit scale adopted was MPa (megapascal). Individualized areas of interest represent implant contact area on the bone tissue, ligament, and lamina dura cortical bone. It was possible to observe maximum values close to 11 MPa and -3.7 MPa for tensile stress and compression in the bone tissue implant contact area in the TitaniumFix implant model, respectively, and 7.9 MPa and -2.3 MPa for the Neodent implant model (Figure 4).

The periodontal ligament presented low values of maximum principal stress, with compression and tensile areas visualized with a scale between values of 0.1 to -0.1 MPa. Even with low values, it was possible to observe a tendency of compression in the distal root mesiobuccal region and in the disto-lingual region, with both being close to the furcation area. On the other hand, there was a tensile stress area in the mesial root distobuccal areas. The tensile stress and compression areas were the same internally, indicating a clockwise rotation tendency of the tooth which received the orthodontic force. Both mini-implants showed similar results. The results using TitaniumFix mini-implant is illustrated in Figure 5.

It was possible to observe that the stress transmission in the cortical bone was quite low. However, some specific areas in the image (Figure 6) should be highlighted. As shown, the maps were very similar, and both presented a slightly more pronounced compression region near the mesial root distal-lingual region, close to the furcation. Moreover, a more pronounced tensile stress area near the distal root mesial buccal region, indicating a force moment which tends to turn the molar clockwise, as seen in the ligament.

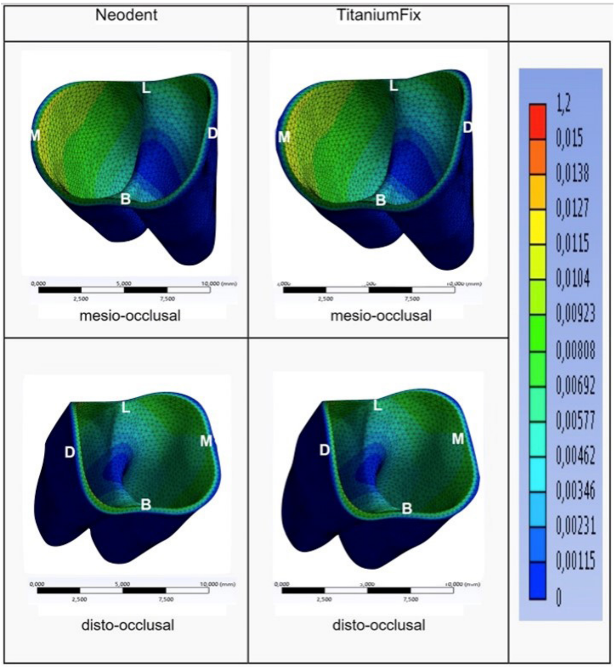

Figure 3 - Periodontal ligament displacement maps (scale units in millimeters). Legend: M) mesial; D) distal; B) buccal; L) lingual.

DISCUSSION

There has been a significant increase in the demand of adult patients looking for orthodontic treatment in recent years. This demand is not only for aesthetic corrections, but also for occlusion rehabilitation and satisfactory mastication. In this context, the first lower molar loss has been observed, followed by a consequent natural movement of the second molar crown [6,19,20]. In this study, the near ideal mini-implant

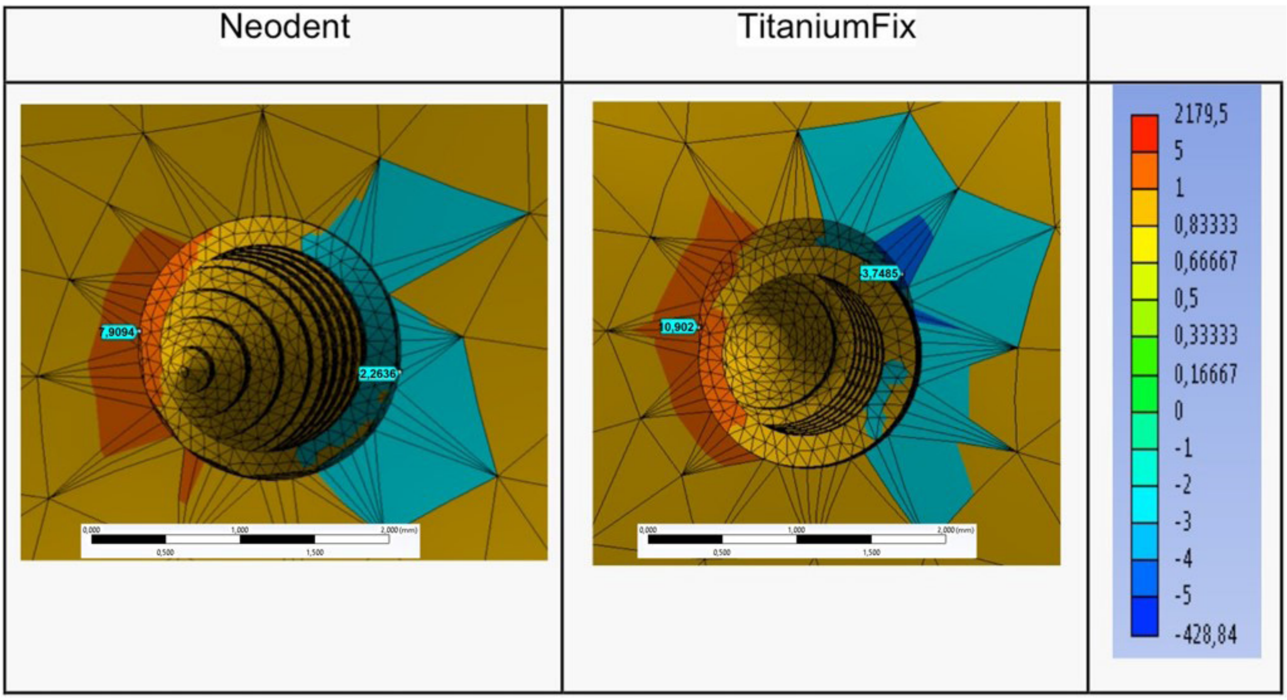

Figure 4 - Cortical and trabecular bone maximum principal stress maps of the contact region with the mini-implant (scale unit in MPa).

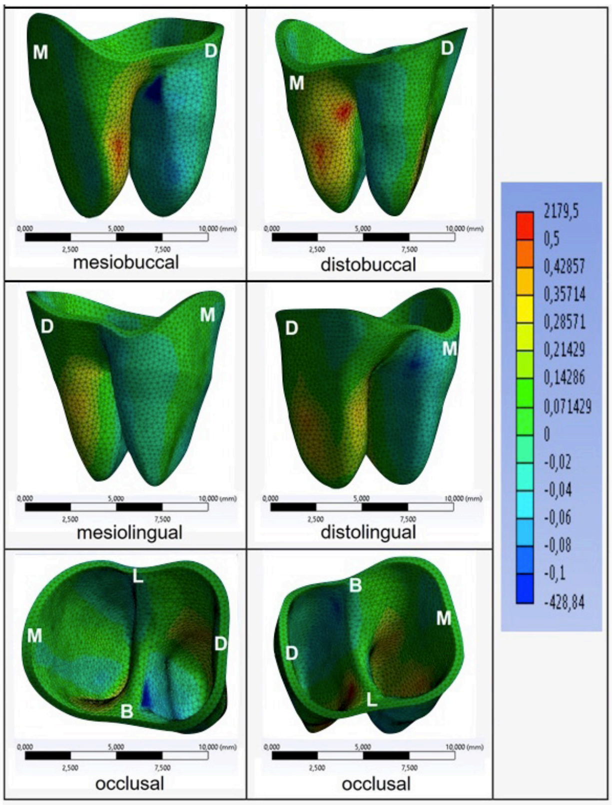

Figure 5 - Maximum principal stress maps of the periodontal ligament in several views (scale unit in MPa). Legend: M) mesial; D) distal; B) buccal; L) lingual.

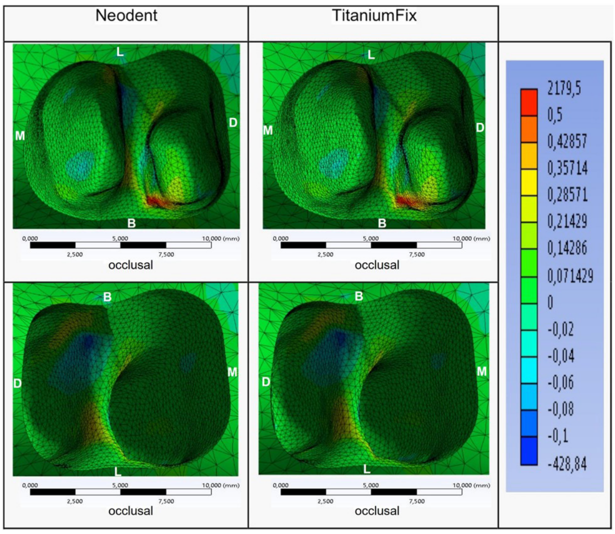

Figure 6 - Cortical bone maximum principal stress maps in several views (scale units in MPa). Legend: M) mesial; D) distal; B) buccal; L) lingual.

positioning situation was simulated at 1 mm apically to the molar furcation, and technically using action-reaction pair on the mini-implant's neck embrasure mesial surface and the distal embrasure of the orthodontic device as a simple elastic for orthodontic movement. This situation is near to what is clinically expected and achieved by clinicians.

Some studies have shown that lower molar orthodontic mesialization is a mechanical action which rehabilitates edentulous spaces when used with caution and considering limitations and individuality of each case, thereby leading to the possibility of treatment for the patient [6,21]. That said, it is possible to state that this fact corroborates the results found in this study as the applied force showed a tendency to move the dental element. The movement action can be observed in maximum principal stress maps, mainly of cortical bone (Figure 6). A compression zone on cortical bone will generate a resorptive area and a tensile stress zone on the opposite area of bone when considering orthodontic forces of low intensity and continuously. As compressive zones were located at the distal-lingual region of mesial root contact and tensile stress zones on the mesial-buccal region of distal root, a spin of the root is expected when the forces are applied to the mesial direction which could be transferred in a straight move by use on orthodontic wires to guide the movement.

Mini-implants have been proven to be effective as an anchorage method in orthodontics, and it is possible to extend treatment possibilities, as well as to make orthodontics cases which used traditional anchoring methods considered complex easier [22]. There are many reports in the scientific literature reporting success in the use of mini-implants in different tooth movement situations in both the mandible and in the maxilla [23,24]. This is also in agreement with the findings of this study, in which mini-implants were effective in lower molar mesialization anchorage.

The distal buccal region selected for the second pre-molar used for installing the mini-implants was made taking into account works which emphasize the importance of inserted gingiva and adequate amount of cortical bone [25]. The ideal location for mini-implants in molar mesialization is the premolar distal (edentulous space) or between the premolar roots [20]. It is preferably installed as close as possible to the occlusal plane in order to reduce the mesial molar intrusive vector and consequently its inclination [6].

The resistance center location of a tooth varies according to root length and radicular morphology, number of roots and level of supported alveolar bone [20]. Considering molars, the resistance center is located approximately 1 mm apical to the furcation [6]. A power-arm was incorporated to the orthodontic tube in order to apply the load as close as possible to the resistance center, optimizing the translation movement with radicular parallelism.

Considering that physiological limits for cortical bone are around 140 to 170 MPa for compression stress, and 72 to 76 MPa for tensile stress [26], it was observed that the installation area chosen and the mini-implant measurements were adequate for the purpose of this study. This is because the bone tension and compression values found around the mini-implants were lower (varying between -3.7 MPa to 11 MPa), which suggests that used devices had no tendency to resorption.

The optimal force for orthodontic tooth movement should stimulate cell activity without completely occluding blood vessels. The periodontal ligament response is not only determined by force, but also by the pressure distribution produced by the applied force per unit of radicular area [22].

The applied force of 200cN was chosen based on previous studies [19,20,27], and it generated compression and tensile stress areas around the dental root, leading it to a clinical situation. It is believed that these areas indicate places where bone remodeling will occur, assuming a tendency to mesial tooth movement.

There was a greater tendency of movement in the distal root mesial buccal region, which suggests a molar rotation clockwise, as shown in Figures 5-6. This undesired effect was expected and could be avoided in clinical practice or also through the installation of mini-implant by lingual region [6].

The study of loads and movements through FEA is of great importance. Since it is a mathematical, theoretical, and comparative study, much analysis could be used in order to try to demonstrate actions and reactions of any model. Thus, an action and reaction pair was used in this study, which could simulate the real relation between elastic ligature, since there are two opposite forces acting in dental movement.

However, it is known that this movement occurs by the action of these forces. In fact, it is not a long-term analysis, and it is understandable that there is not a single dental chair time capable of conducting the entire orthodontic movement, since force is generated in each appointment to induce movement.

In addition, it must be emphasized that movement simulation following the orthodontic wire is warranted by the restrictions made in movement direction, which was restricted in the model. Opposite forces following a described vector were applied, however any movement of force which should not be along this vector line pair was restricted. This is an engineering consideration, and it is possible to consider it plausible since two pairs of forces were used, one for each dental button area (upper and lower areas).

Regarding these aspects of FEA, there is a need for biomechanical studies that investigate the movement quantity and efficiency in different situations, as well as the metabolic condition interference and systemic factors, such as diseases which affect bone metabolism and diabetes in the dental movement process, reviewing the specific literature [28]. This technique has some limitations, including the need for correct values for materials involved in the study, the application of forces which is an approximation of clinical use for molar mesialization, and mainly that is a computer technique which simulates a biological situation using a static analysis in this study, but that is a continuous movement in clinical reality. Thus, the data presented should be extrapolated with caution to the daily orthodontic clinic. There are few reports in the literature regarding molar mesialization movement, which demonstrates how little this mechanism is used in dental reality. The lack of knowledge about this technique and the difficulty of finding a scientific basis could be a reason why specialists discard this treatment option. This paper intends to collaborate for this scenario, aiming at changing this situation. Lastly, more studies are needed in order to provide the possibility of this mechanism being incorporated into dental routines.

CONCLUSION

According to the methodology used and within the limitations of this study, it is possible to conclude:

- The mini-implants tested showed similar results and achieved the expected performance;
- The load tested was effective to induce the distribution of stress in the bone tissue, which shows a tendency of dental displacement occurring in the mesial direction;
- The stress distribution around the mini-implants shows that the device characteristics used in this study are in agreement in order to promote an effective anchorage for the studied movement;
- The design used demonstrated that a clockwise movement is expected during movement;
- The movement created theoretically allows the second molar to take the location of the first molar.

Author's Contributions

JMFS, RMA, FRV: Conceptualization. JCL, RMA, CAAL, RSC, FRV: Methodology. JCL, CAAL, RSC: Data Curation. JMFS, JCL, FZP, FRV: Writing - Review & Editing. JMFS, FRV: Supervision.

Conflict of Interest

No conflicts of interest declared concerning the publication of this article.

Funding

The authors declare that no financial support was received.

Regulatory Statement

Not applicable.

REFERENCES

1. Normando D, Cavacami C. The influence of bilateral lower first permanent molar loss on dentofacial morfology: a cephalometric study. Dental Press J Orthod. 2010;15:100-6. http://dx.doi.org/10.1590/S2176-94512010000600013.
2. Sousa ASD, Araújo FRL, Villela GSC, Normando D. Impact of early loss of lower first permanent molars on third molar development and position. Pesqui Bras Odontopediatria Clin Integr. 2021;21:e0072. http://dx.doi.org/10.1590/pboci.2021.050.
3. Pedroso JF, Lima DR, Lima FR, Pazinatto R. Multidisciplinary treatment: association among orthodontics, implantodontia and prosthetics. Case report. Braz Dent Sci. 2018;21(3):357-64. http://dx.doi.org/10.14295/bds.2018.v21i3.1552.
4. Pithon M. Severe hemorrhage in a patient with dengue hemorrhagic fever after insertion of orthodontic mini-implants. A case report. Braz Dent Sci. 2020;23(4):1-7. http://dx.doi.org/10.14295/bds.2020.v23i4.1952.
5. Felicita AS, Ravi S. Distalization of the entire maxillary arch with mini-implants in the posterior palatal alveolus-a case report. Braz Dent Sci. 2020;23(3):1-9. http://dx.doi.org/10.14295/bds.2020.v23i3.1946.
6. Janson M, Silva DAF. Mesial movement of molars with mini-implants anchorage. Dental Press Ortodon Ortop Facial. 2008;13:88-94. http://dx.doi.org/10.1590/S1415-54192008000500009.
7. Lima LAC, Lima C, Lima V, Lima V. Absolute anchorage with mini-implants: improving the concepts of the orthodontic mechanics. Innov Implant J Biomater Esthet. 2010;5:85-91.
8. Drago CJ. Use of osseointegrated implants in adult orthodontic treatment: a clinical report. J Prosthet Dent. 1999;82(5):504-9. http://dx.doi.org/10.1016/S0022-3913(99)70045-4. PMid:10559718.
9. Marassi C, Marassi C. Mini-implantes ortodônticos como auxiliares da fase de retração anterior. Dental Press Ortodon Ortop Facial. 2008;13(5):57-75. http://dx.doi.org/10.1590/S1415-54192008000500007.
10. Crismani AG, Bertl MH, Čelar AG, Bantleon HP, Burstone CJ. Miniscrews in orthodontic treatment: review and analysis of published clinical trials. Am J Orthod Dentofacial Orthop. 2010;137(1):108-13. http://dx.doi.org/10.1016/j.ajodo.2008.01.027. PMid:20122438.
11. Liu TC, Chang CH, Wong TY, Liu JK. Finite element analysis of miniscrew implants used for orthodontic anchorage. Am J Orthod Dentofacial Orthop. 2012;141(4):468-76. http://dx.doi.org/10.1016/j.ajodo.2011.11.012. PMid:22464529.
12. Elias CN, Ruellas ACO, Fernandes DJ. Orthodontic implants: concepts for the orthodontic practitioner. Int J Dent. 2012;2012:549761. http://dx.doi.org/10.1155/2012/549761. PMid:23209470.
13. Liu Z, Sun T, Fan Y. Biomechanical influence of anchorages on orthodontic space closing mechanics by sliding method. Med Biol Eng Comput. 2020;58(5):1091-7. http://dx.doi.org/10.1007/s11517-020-02149-1. PMid:32162244.
14. Chatzigianni A, Keilig L, Duschner H, Götz H, Eliades T, Bourauel C. Comparative analysis of numerical and experimental data of orthodontic mini-implants. Eur J Orthod. 2011;33(5):468-75. http://dx.doi.org/10.1093/ejo/cjr097. PMid:21852288.
15. Knox J, Jones ML, Hubsch P, Middleton J, Kralj B. An evaluation of the stresses generated in a bonded orthodontic attachment by three different load cases using the finite element method of stress analysis. J Orthod. 2000;27(1):39-46. http://dx.doi.org/10.1093/ortho/27.1.39. PMid:10790443.
16. Verri FR, Okumura M, Lemos C, Almeida D, Batista VES, Cruz RS, et al. Three-dimensional finite element analysis of glass fiber and cast metal posts with different alloys for reconstruction of teeth without ferrule. J Med Eng Technol. 2017;41(8):644-51. http://dx.doi.org/10.1080/03091902.2017.1385655. PMid:29043866.
17. Verri FR, Cruz RS, Batista VES, Almeida DA, Verri AC, Lemos CA, et al. Can the modeling for simplification of a dental implant surface affect the accuracy of 3D finite element analysis? Comput Methods Biomech Biomed Engin. 2016;19(15):1665-72. http://dx.doi.org/10.1080/10255842.2016.1176156. PMid:27082041.
18. Ludwig B, Baumgaertel S, Zorkun B, Bonitz L, Glasl B, Wilmes B, et al. Application of a new viscoelastic finite element method

model and analysis of miniscrew-supported hybrid hyrax treatment. Am J Orthod Dentofacial Orthop. 2013;143(3):426-35. http://dx.doi.org/10.1016/j.ajodo.2012.07.019. PMid:23452978.

19. Matteo RC, Villa N, Sendyk WR. Mandibular molar uprighting, using mini-screw as anchorage. Dental Press Ortodon Ortop Facial. 2005;10:124-33. http://dx.doi.org/10.1590/S1415-54192005000400013.

20. Scardua MT. Protocolo para mesialização de molares inferiores com mini-implantes. Rev Clín Ortod Dental Press. 2011;10:95-106.

21. Muller C, Cruz CM, Crepaldi MV, Dainesi EA, Souza JEP. Mesialização de molares com auxílio de mini parafuso: relato de caso. Rev Faipe. 2017;6:50-60.

22. Araújo TM, Nascimento MHA, Bezerra F, Sobral MC. Skeletal anchorage in orthodontics with mini-implants. Dental Press Ortodon Ortop Facial. 2006;11:126-56.

23. Santos SHB, Poletto-Neto V, Queiroz ABL, Sarkis-Onofre R, Pereira-Cenci T. Failure of miniscrews installed in maxilla and mandible: a systematic review and meta-analysis. Braz Dent Sci. 2020;23(3):1-7.

24. Lira ADLS, Nascimento GP, Freitas TFC. Intrusion of upper molars with mini-implants for open bite correction is effective? A systematic review. Braz Dent Sci. 2018;21(4):461-9. http://dx.doi.org/10.14295/bds.2018.v21i4.1603.

25. Josgrilbert LFV, Henriques JFC, Kayatt FE, Godoy HT, Tirloni P, Henriques RP. A utilização dos mini-implantes na mecânica ortodôntica contemporânea. Rev Clín Ortod Dental Press. 2008;7(4):68-82.

26. Papavasiliou G, Kamposiora P, Bayne SC, Felton DA. Three-dimensional finite element analysis of stress-distribution around single tooth implants as a function of bony support, prosthesis type, and loading during function. J Prosthet Dent. 1996;76(6):633-40. http://dx.doi.org/10.1016/S0022-3913(96)90442-4. PMid:8957790.

27. Consolaro A, Romano FL. Reasons for mini-implants failure: choosing installation site should be valued! Dental Press J Orthod. 2014;19(2):18-24. http://dx.doi.org/10.1590/2176-9451.19.2.018-024.oin. PMid:24945511.

28. Gimenez CMM, Murad L, Meireles BR, Arantes FM, Junqueira JLC, Santos ECA. Main systemic alterations regarding induced dental movement. Rev Gaucha Odontol. 2007;55(2):191-5.

João Maurício Ferraz da Silva
(Corresponding address)
Universidade Estadual Paulista "Júlio de Mesquita Filho", Instituto de Ciência e Tecnologia, Departamento de Materiais Odontológicos e Prótese. São José dos Campos, Brazil.
Email: joao.mauricio@unesp.br

Date submitted: 2022 Apr 13
Accept submission: 2022 Sept 09